Department of Aerospace Engineering
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NUMERICAL SOLUTION FOR THE TEMPERATURE DISTRIBUTION IN A COOLED GUIDE VANE BLADE OF A RADIAL GAS TURBINE

BY

W. HOSNY AND W. TABAKOFF

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16. Abstract

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A simple convection cooling is assumed inside the guide vane blade. Such cooling has relatively small cooling effectiveness at the leading edge and at the trailing edge. Heat transfer augmentation in these critical areas may be achieved by using impingement jets and film cooling.

A computer program is written in Fortran IV for IBM 370/165 computer.

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SUMMARY

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A computer program is written in Fortran IV for IBM 370/165 computer.

INTRODUCTION

In a turbomachine, performance benefits could be achieved with high turbine inlet temperature and high pressure ratio. Efficient expansion from a high pressure requires more than one axial turbine, of which the first one may become exceedingly small. Large tip clearance, thick trailing edge and secondary losses in such small turbines tend to offset the advantages of high inlet temperatures. On the other hand, the small radial turbine has demonstrated an excellent performance at high stage loadings. The power output of a gas turbine is directly proportional to the inlet temperature of the combustion gases. Certainly, higher inlet temperatures are desired in order to achieve higher output. In recognition of this, researchers have devoted considerable efforts to the development of higher temperature blade materials and efficient methods of cooling.

Radial turbine rotor cooling is accomplished by using cooling air passages through each rotor blade. The cooling air is then exhausted at the blade suction surface. The guide vane blades are internally cooled by streams of cooling air which after having cooled the vanes is ejected into the primary gas stream. In general, the different cooling techniques used for axial flow turbines, could be applied as well for radial turbines. For modest increases in turbine inlet temperature, simple convection cooled blades may be used. As further increases in the temperatures are required, the engine designer must use impingement cooling and film cooling techniques. Very high cycle temperature requires consideration of transpiration cooled blades.

Oxidation and thermal creep are forms of failure in turbines with high inlet temperatures. The guide vanes are more exposed to failure by local oxidation than creep and hence are highly influenced by local hot spots. Such areas are usually localized at the leading and trailing edges. A theoretical method for estimating the temperature distribution inside the cooled guide vane blade, using simple convection cooling effectiveness will be presented.

GUIDE VANE COOLING

A radial guide vane does not usually experience a high spanwise temperature gradient at its inlet. In addition, the heat conducted to the two guide vane back plates is also negligible. Therefore, a two dimensional solution for the temperature distribution is acceptable.

The isothermal lines in an uncooled radial guide vane blade are shown in Figure 1 (taken from Ref. 1). In the vicinity of the leading edge, the material temperature is very close to the gas temperature. The blade temperature drops toward the trailing edge. The high temperature at the leading edge region is the result of the high heat transfer coefficient near the stagnation point.

The convection cooling requirements can be determined by considering the blades as heat exchangers and evaluating the heat capacity of the cooling air flow through the vanes. Such analysis will require the solution of the heat conduction equation within the material combined with the heat balance equation for the cooling air.

Obtaining solutions for the heat conduction equation pose some difficulties due to the irregular shape of the vane blade boundary, and the variations in the temperature and the heat transfer coefficient around the surface. Due to the above circumstances, it is necessary to resort to a numerical solution. A finite difference technique similar to Reference 1 will be used. Modification to account for the cooling passage has been introduced.

Convective heat transfer coefficient on both the inner and the outer sides of the blade surface can be estimated theoretically as follows:

Hot gas side heat transfer coefficient (outside the blade):

The heat transfer coefficient could be obtained from the boundary layer characteristics around the guide vane blade. The boundary layer solution is obtained by using the computer program written by Herring and Mellor (Ref. 2). The velocity distribution needed for the boundary layer calculations is determined using the computer program given by Katsanis (Ref. 3), assuming

that the amount of heat transfered to the coolant from the hot gases will not affect the flow behavior around the blade. The heat transfer coefficient is then determined using the Reynolds analogy. Figures 2, 3 and 4 show respectively the gas velocity, temperature and heat transfer coefficient distribution on the outside surface of the guide vane blade.

Cooling side heat transfer coefficient (inside the vane):

The cooling air passes usually through axial hole passages of constant area, large enough to ensure turbulent flow. Thus the heat transfer coefficient for simple convection cooling could be estimated from the conventional formula given in Reference 4,

$$Nu = 0.02\ Re^{0.8} \left(\frac{T_s}{T_c}\right)^{0.49}$$

where

$$Nu = \frac{hD}{k} \quad , \qquad Re = \frac{\rho V D}{\mu}$$

T_s is the material temperature on the cooling side surface

D is the hydraulic diameter of the cooling passage.

For other patterns of cooling the heat transfer correlation for flow between plates could be used, which is given as:

$$Nu = 0.014\ Re^{0.81}$$

If impingement cooling is used, the semi empirical correlation, given in Reference 5 could be used to determine the convective heat transfer coefficient.

GOVERNING EQUATIONS AND FINITE DIFFERENCES

In the rectangular coordinate system, the differential equation governing the steady state two dimensional temperature distribution is given by

$$\frac{\partial}{\partial X}\left(k\,\frac{\partial T}{\partial X}\right) + \frac{\partial}{\partial Y}\left(k\,\frac{\partial T}{\partial Y}\right) = 0 \qquad (1)$$

In the above equation it is assumed that there is no heat generation in the blade body. Further simplifications could

result by assuming constant thermal conductivity, corresponding to the vane blade average temperature. Consequently, the heat equation could be reduced to:

$$\frac{\partial^2 T}{\partial X^2} + \frac{\partial^2 T}{\partial Y^2} = 0 \tag{2}$$

The heat balance equation written at a point on the outside surface is:

$$k \frac{\partial T}{\partial n} = h_g (T_g - T_s) \tag{3}$$

where n is the normal to the blade surface at the point under consideration.

The heat balance equation at the blade inner surface is given by

$$k \frac{\partial T}{\partial n} = h_c (T_c - T_s) \tag{4}$$

Equation (2) is an elliptic equation, the boundary conditions are given by Equations (3) and (4). Each boundary condition relates the temperature gradient normal to the surface to the local surface temperature. Such boundary conditions are of the Fourier type, relating the local heat transfer to the temperature on the boundary.

To solve equation (2), one has to use either finite difference or finite element technique. In this study the first approach is used to obtain the solution. For any grid point P, as shown in Figure 5, the partial differential equation (2) can be written in the finite difference form in terms of the temperatures at the points A, B, C, D and P. The points A and C are located at ε_1, ε_2 fractions of DX, while the points B and D are located at δ_1 and δ_2 fractions of DY from the mesh point P. For equally spaced grid points, the factors ε_1, ε_2, δ_1 and δ_2 will be equal to 1.0. The finite difference equation is given by:

$$\frac{2}{DX^2(\varepsilon_1 + \varepsilon_2)} \left[\frac{T_{i-1,j}}{\varepsilon_1} - T_{i,j}\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2}\right) + \frac{T_{i+1,j}}{\varepsilon_2}\right]$$

$$+ \frac{2}{DY^2(\delta_1 + \delta_2)} \left[\frac{T_{i,j-1}}{\delta_1} - T_{i,j}\left(\frac{1}{\delta_1} + \frac{1}{\delta_2}\right) + \frac{T_{i,j+1}}{\delta_2}\right] = 0 \qquad (5)$$

which could be written in a more convenient form as:

$$T_{i,j} = \frac{1}{E} \left\{\frac{T_{i-1,j}}{\varepsilon_1(\varepsilon_1+\varepsilon_2)} + \frac{T_{i,j+1}}{\varepsilon_2(\varepsilon_1+\varepsilon_2)} + \left(\frac{DX}{DY}\right)^2 \left[\frac{T_{i,j-1}}{\delta_1(\delta_1+\delta_2)} + \frac{T_{i,j+1}}{\delta_2(\delta_1+\delta_2)}\right]\right\} \qquad (6)$$

where

$$E = \left[\frac{1}{\varepsilon_1 \varepsilon_2} + \left(\frac{DX}{DY}\right)^2 \frac{1}{\delta_1 \delta_2}\right] \qquad (7)$$

The above equations are second order accurate when $\delta_1 \approx \delta_2$ and $\varepsilon_1 \approx \varepsilon_2$.

At the blade boundary points, such as the point D shown in Figure 6, the convective boundary condition given by Equation (3) or (4) could be written in the following finite difference form:

$$\frac{\partial T}{\partial n} = \frac{T_D - T_N}{DN} = \frac{h_{g,c}}{k} (T_{g,c} - T_D) \qquad (8)$$

i.e.

$$T_D = \frac{\left[T_N + \frac{h_{g,c}\, DN}{k} T_{g,c}\right]}{\left[1 + \frac{h_{g,c}}{k} DN\right]} \qquad (9)$$

where

T_D is the material temperature at the inner or outer surface point D;

T_N is the material temperature at the interior point N;

and g,c are subscripts for gas or cooling flow.

Solution of Equation (6) along with Equation (9) using suitable iteration technique would give the temperature distribution in the internally cooled blade.

COMPUTER PROGRAM

The details of the input to the computer program are given in Appendix A. Initially, the temperature matrix T is set to any conveniently chosen temperature. The iteration then proceeds using the Gauss-Seidel method. Temperatures at the interior points are calculated by subroutine "MESH", while boundary point temperatures are calculated in the main program. Referring to Figure 7, the calculation of the boundary temperatures proceed for each of the I lines and then in a similar manner for each of the J lines. The iteration process is repeated until the sum of the squares difference between two successive iterations is less than a prescribed value,

i.e.

$$\sum_{\text{all points}} (T_N - T_{N-1})^2 \leq \varepsilon \tag{10}$$

Where T_N is the temperature after the N iteration;

T_{N-1} is the temperature after the (N-1) iteration;

and ε is the prescribed error limit.

The process of convergence could be accelerated by using an over-relaxation factor, ω, in the following formula:

$$T_N = \omega\, T_N' + (1 - \omega) T_{N-1} \tag{11}$$

Where T_{N-1} is the temperature after (N-1) iterations;

T_N' is the temperature computed after N iterations;

ω is the over-relaxation factor;

T_N is the temperature used for the (N+1) iteration.

The optimum over-relaxation factor is determined from different trials. Figure 8 gives the variation in the number of iterations, needed for certain convergence limit, with the relaxation factor. The number of iterations is significantly reduced from 440 at $\omega = 1.0$ to about 140 for $\omega = 1.6$.

After the final iteration, all the temperatures at the grid points are printed and the isothermals are found by linear interpolation.

The computer program could be used for simple internal cooling. It can also be used for internal cooling with jet impingement. For film cooling, the program can be used after some modifications to include the dimensions and configuration of the injection slots.

RESULTS AND DISCUSSION

The turbine blade and the grid network used in these calculations are shown in Figure 7. The blade inner and outer boundary surface coordinates and its material properties are given in Table I.

The velocity, temperature and heat transfer coefficient distribution on the outer surface are shown in Figures 2, 3 and 4 respectively. The heat transfer coefficient on the inner surface was determined for cooling air to hot gas mass flow ratio of two percent. These different data are used as input to the computer program to calculate the blade material temperature distribution. The program is listed in Appendix C and is written in FORTRAN IV for an IBM 370/165 computer.

A sample output of the program is given in Appendix B. The coordinates of the boundary points through which a least square parabolic curve is fitted are printed in the output. This serves as a check on the program input parameters. The mean square average error is also printed for every iteration, making it possible to monitor the convergence process. After the final iteration, the internal grid temperatures and the surface temperatures are printed as well as the isothermal lines coordinates.

The isothermal lines for the guide vane blade with single central cooling passages are shown in Figure 9. The difference between the maximum and minimum blade temperature was around 400°R. The thermal performance of the cooled guide vane blades can be described by evaluating the surface local cooling effectiveness. The cooling effectiveness on a surface point is defined as:

$$\eta = \frac{T_g - T_s}{T_g - T_c}$$

Figure 10 shows the cooling effectiveness distribution along the blade surface length, for the convex and concave surfaces of the guid vane blade. It is clear that simple convection cooling has relatively small cooling effectiveness at the leading and trailing edges. In these areas other cooling methods have to be used if high local metal temperatures are to be avoided. At the leading edge, the cooling can be enhanced by application of jet impingement to provide high local cooling heat transfer coefficient. A cooling improvement may be achieved at the trailing edge by using film cooling. It can thus be concluded that simple convection cooling is only a primary means of cooling radial guide vanes, it must be enhanced by film cooling slots and impingement jets in critical areas.

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NOMENCLATURE

D	Hydraulic diameter
A,B,C,D	Points indicated in Figure 5
DN	Distance along normal to surface of blade (Figure 3) (inches)
DX	Grid spacing in x direction (inches)
DY	Grid spacing in y direction (inches)
E	Constant defined by Equation (7)
h	Heat transfer coefficient $(\frac{Btu}{hr\ in^2\ °F})$
I	Grid line numbers in x direction
J	Grid line numbers in y direction
k	Thermal conductivity of material of the blade $(\frac{Btu}{hr\ in\ °F})$
n	Normal direction to the blade surface
Nu	Nusselt Number
P	A point of grid structure as in Figure 5
Re	Reynolds number of the flow inside cooling passage.
T	Temperature
V	Velocity inside the cooling passage
X	X-coordinate
Y	Y-coordinate
ρ	Density of cooling air
δ_1	Fraction of grid spacing for point B in Figure 5
δ_2	Fraction of grid spacing for point D in Figure 5
ζ_1	Fraction of grid spacing for point A in Figure 5
ζ_2	Fraction of grid spacing for point C in Figure 5
ε	Error term as defined in Equation (10)

Subscripts:

C	Cooling air
D	Corresponds to boundary point in Figure 6
g	Corresponds to gas
i,j	Mesh line numbers in x and y directions
N	Corresponds to the point where normal to the boundary at D cuts the mesh line AP (Figure 6)
S	Surface

TABLE I

PARTICULARS OF RADIAL TURBINE NOZZLE BLADE:

Leading edge Radius = 0.0815 in

Trailing edge Radius = 0.0157 in

c = 1.94 in

Thermal conductivity = $12 \dfrac{\text{Btu}}{\text{hr ft °F}}$

Boundary points:

X in	Y (Lower) in	Y (Upper) in
0.0	0.100	0.100
0.1	0.028	0.180
0.2	0.025	0.203
0.4	0.068	0.233
0.6	0.105	0.249
0.8	0.133	0.255
1.0	0.148	0.250
1.2	0.155	0.238
1.4	0.147	0.215
1.6	0.127	0.183
1.8	0.100	0.143
1.94	0.100	0.100

DX = o.050 in ; DY = 0.025 in

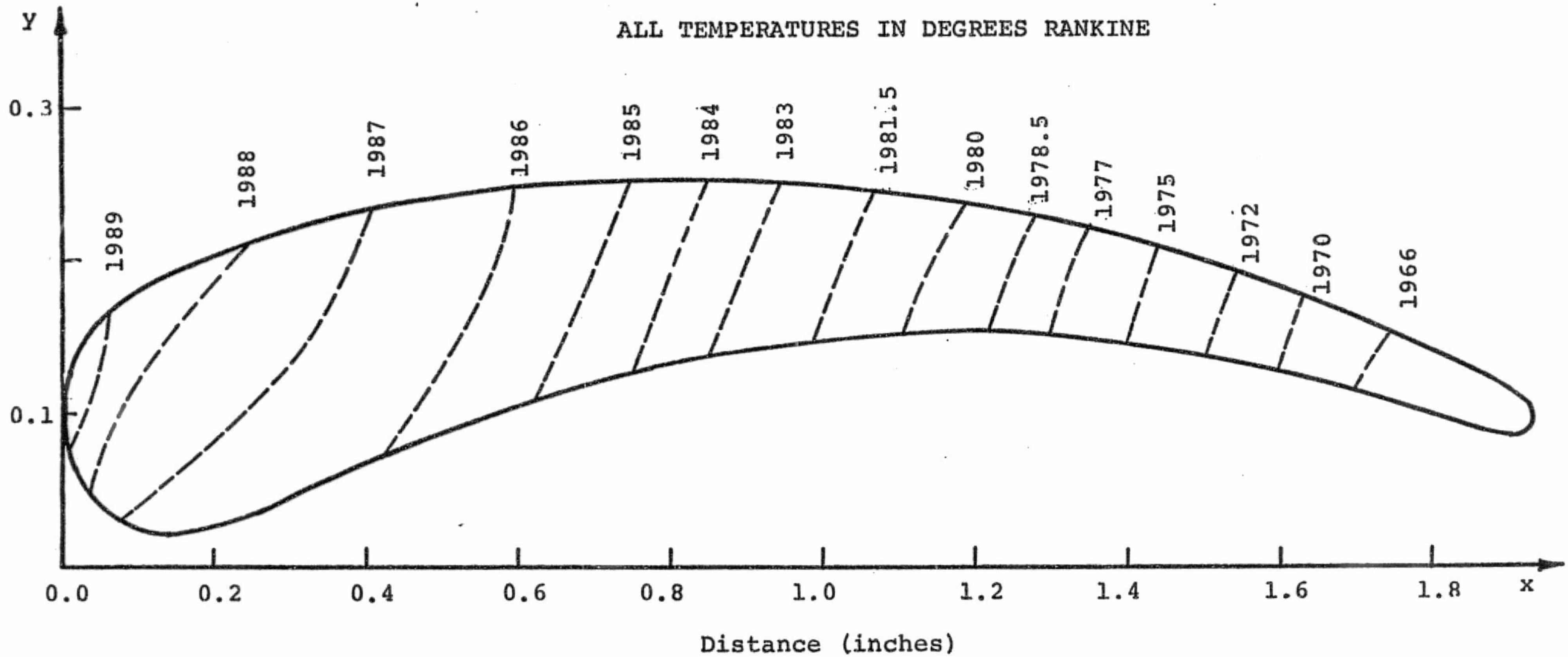

FIGURE 1. ISOTHERMAL LINES IN THE UNCOOLED BLADE.

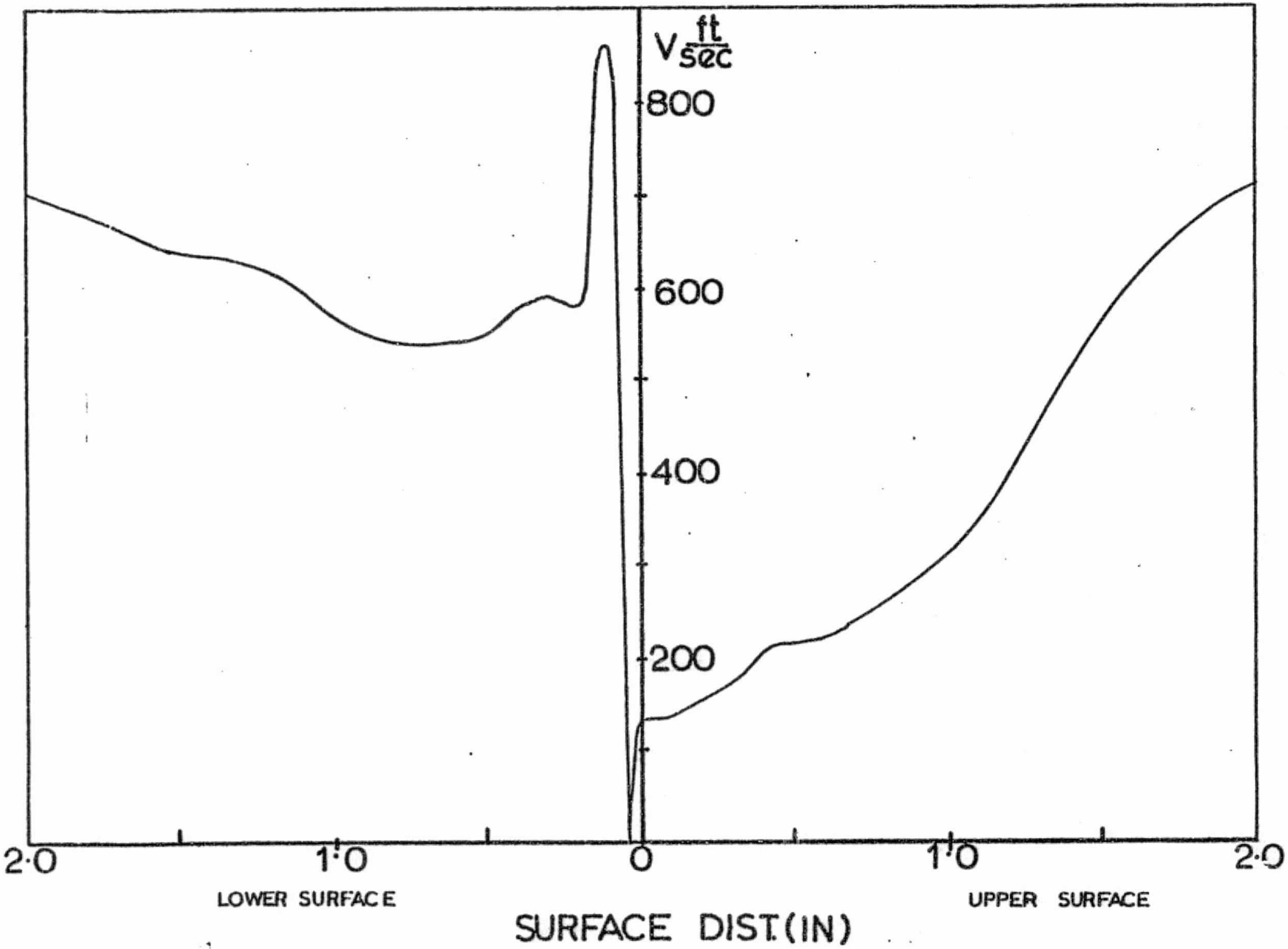

FIGURE 2 VELOCITY DIST. AROUND THE BLADE

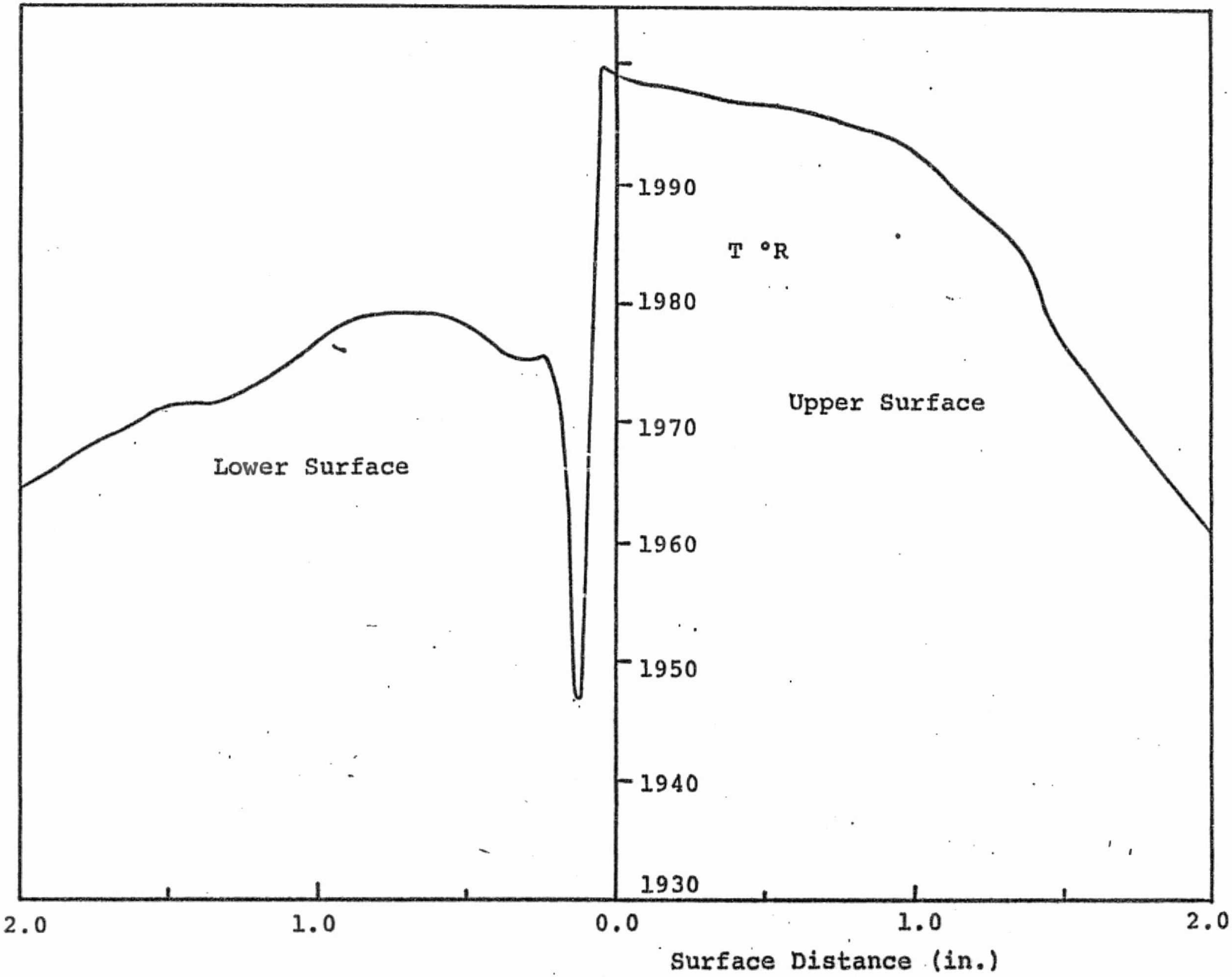

FIGURE 3. STATIC GAS TEMPERATURE DISTRIBUTION AROUND THE BLADE.

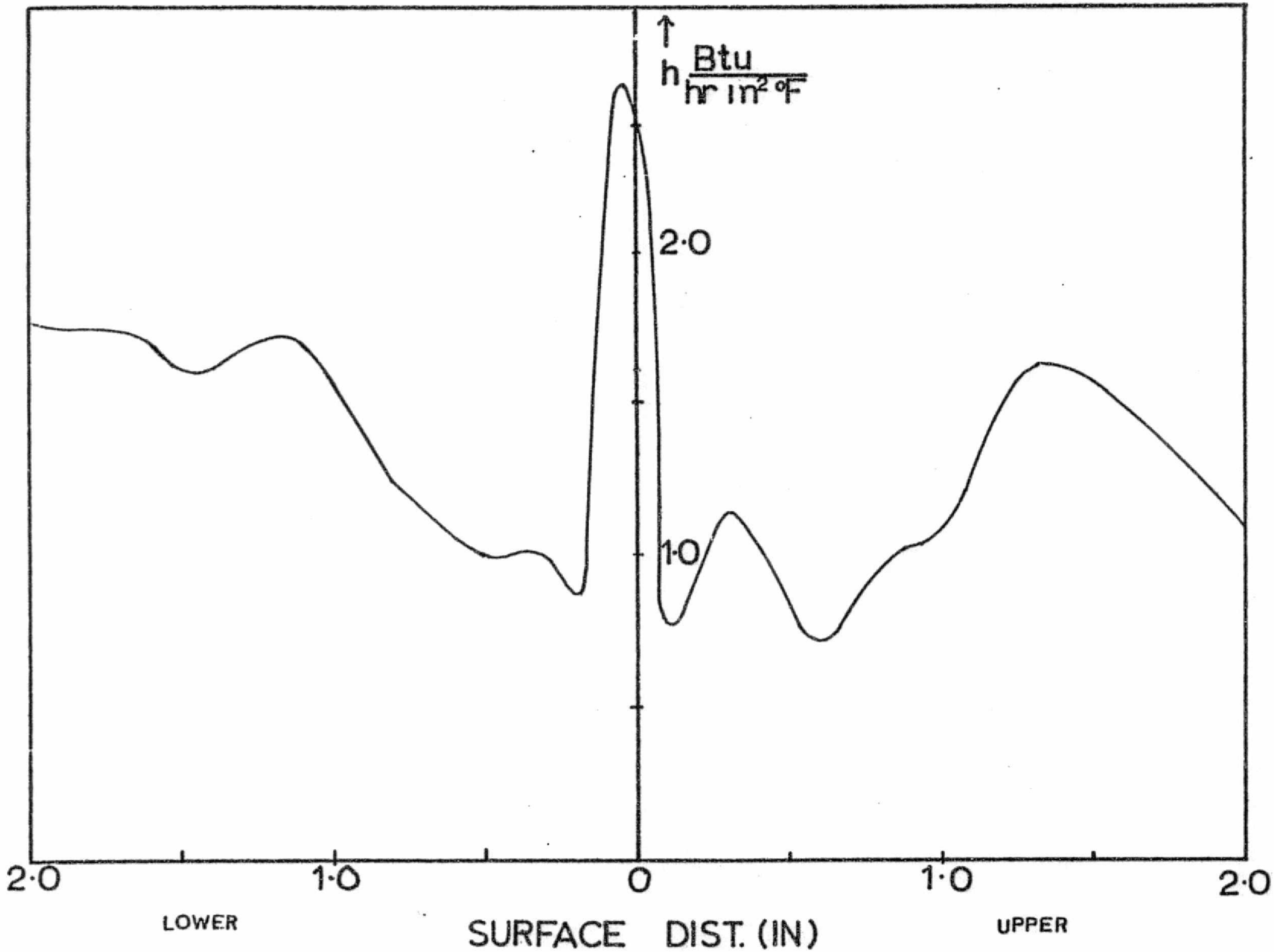

FIGURE 4 HEAT TRANSFER COEFF. AROUND THE BLADE

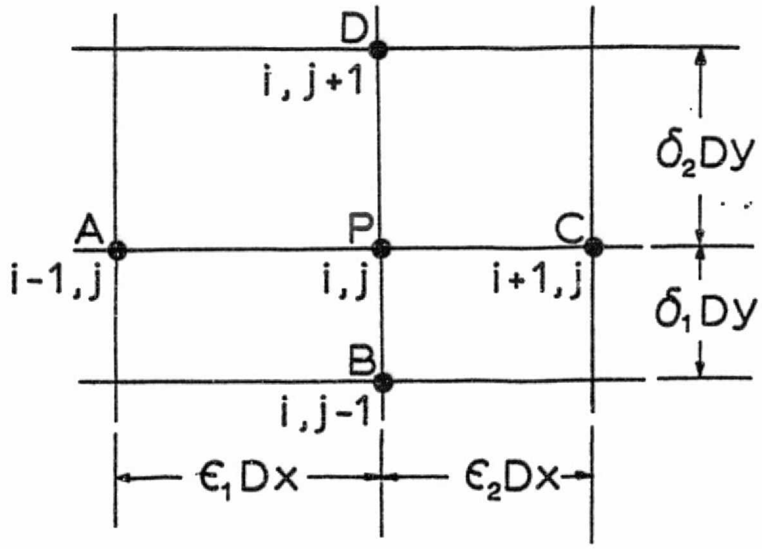

FIGURE 5 GENERAL GRID POINT WITH UNEQUAL SPACINGS

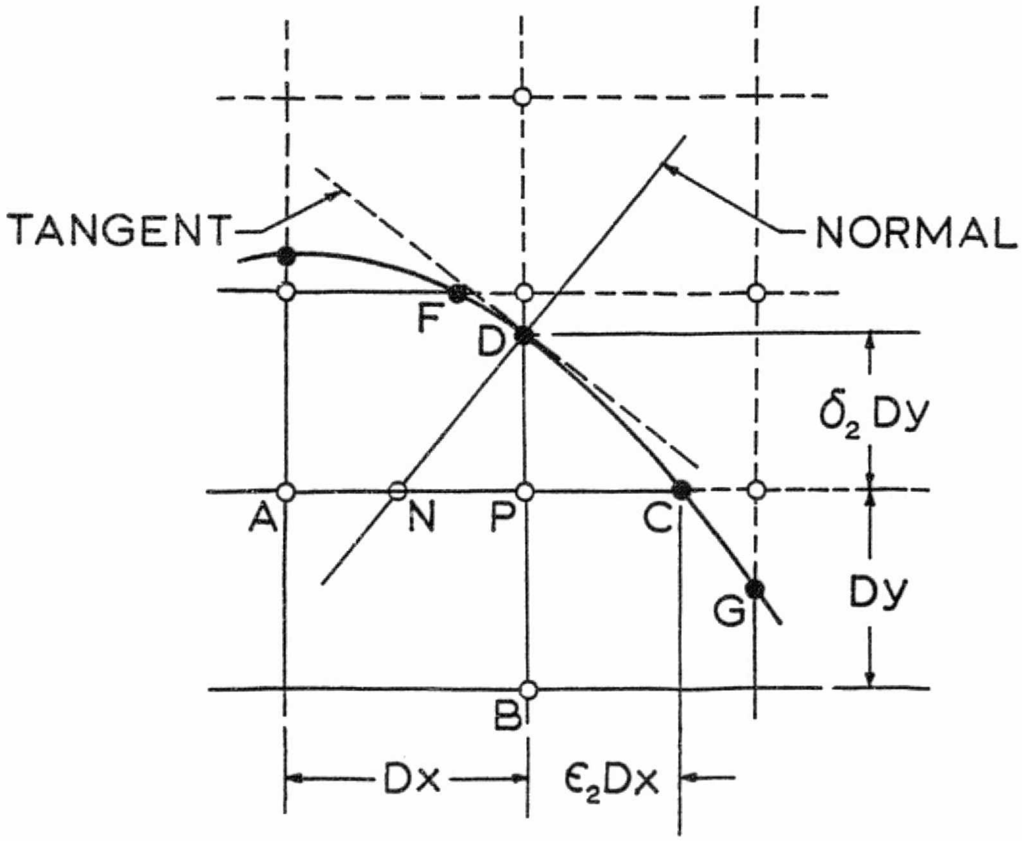

FIGURE 6 POINTS ON A BOUNDARY

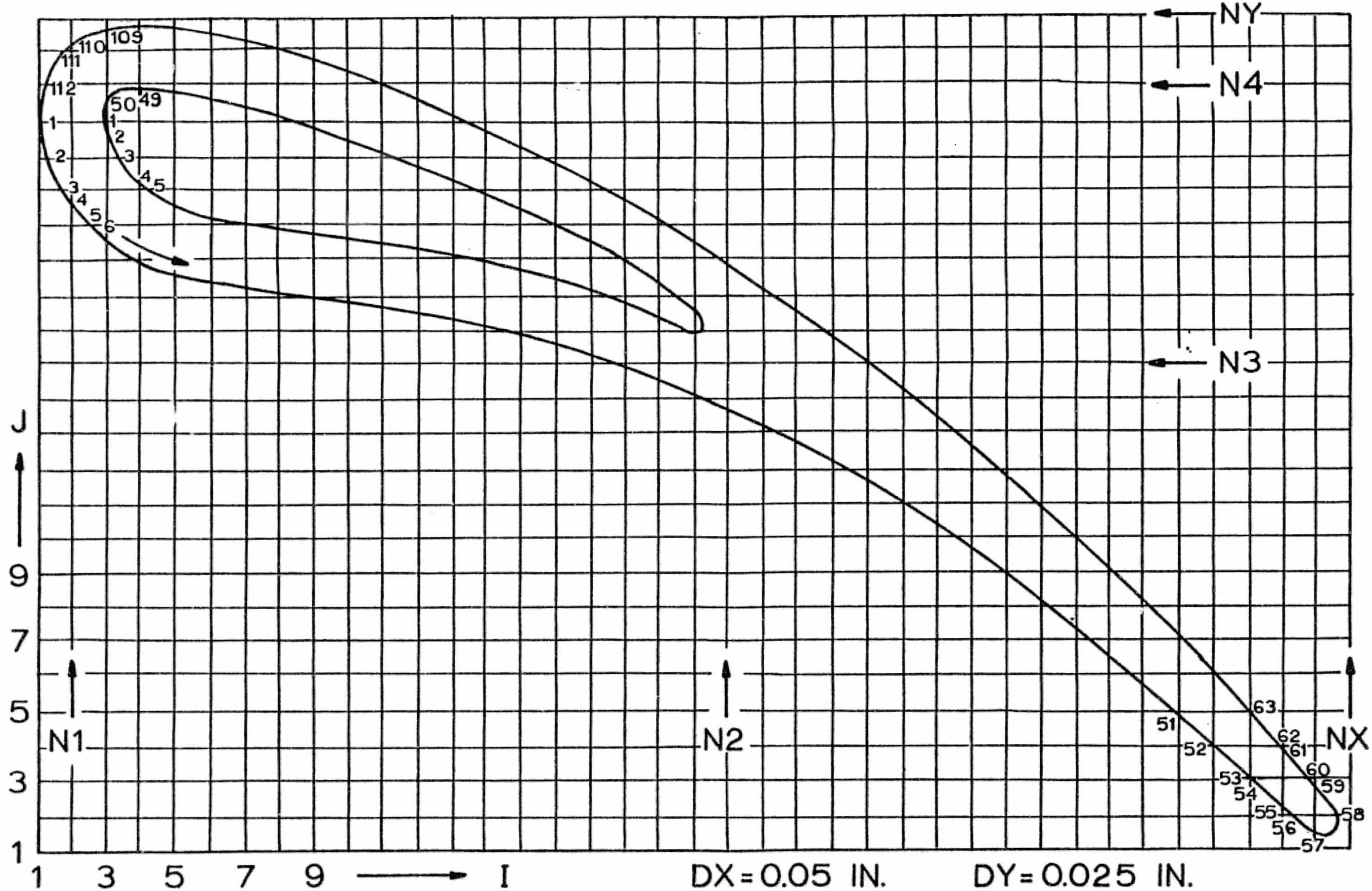

FIGURE 7 BLADE GRID NETWORK

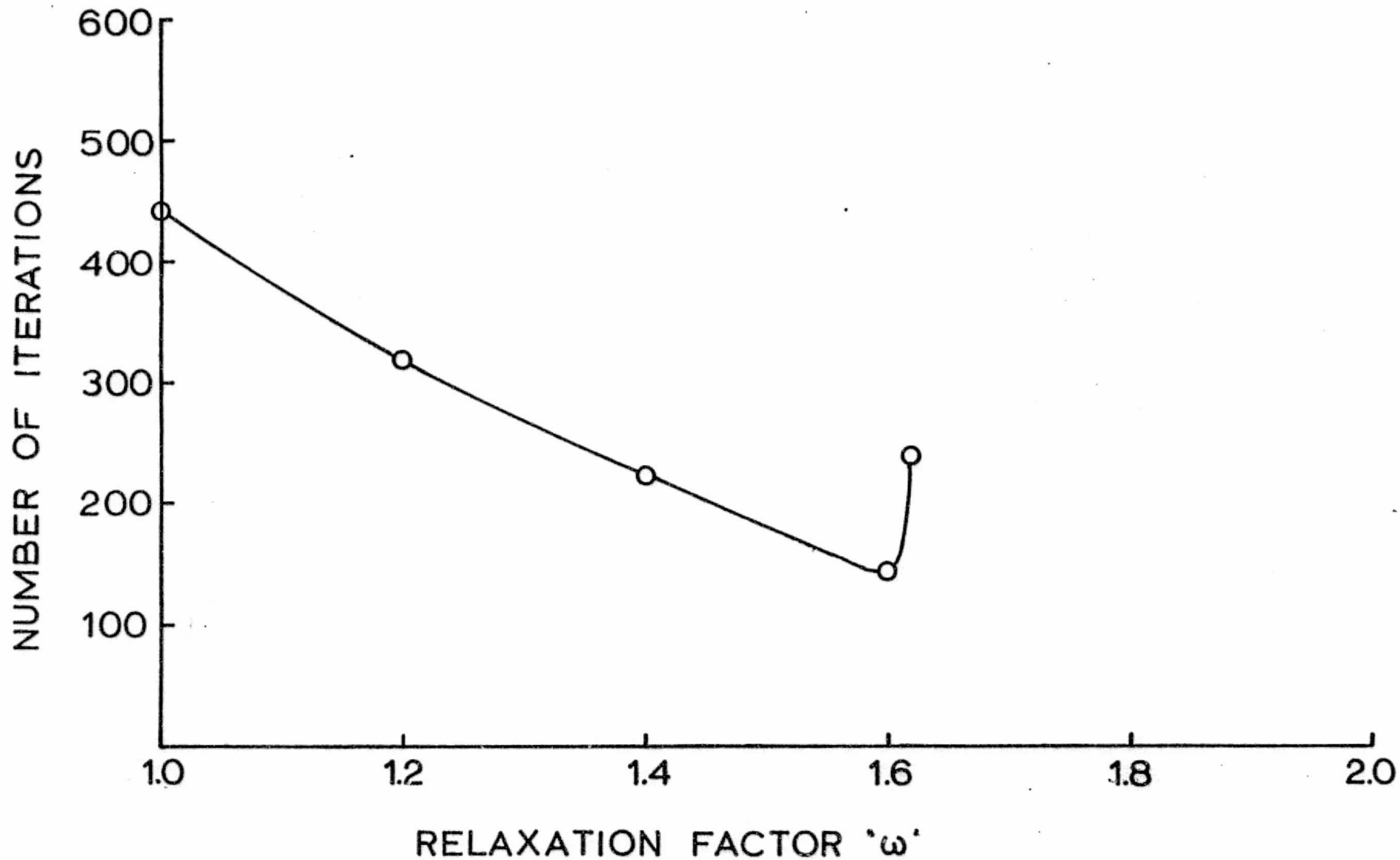

FIGURE 8 VARIATION OF NUMBER OF ITERATIONS WITH 'ω'

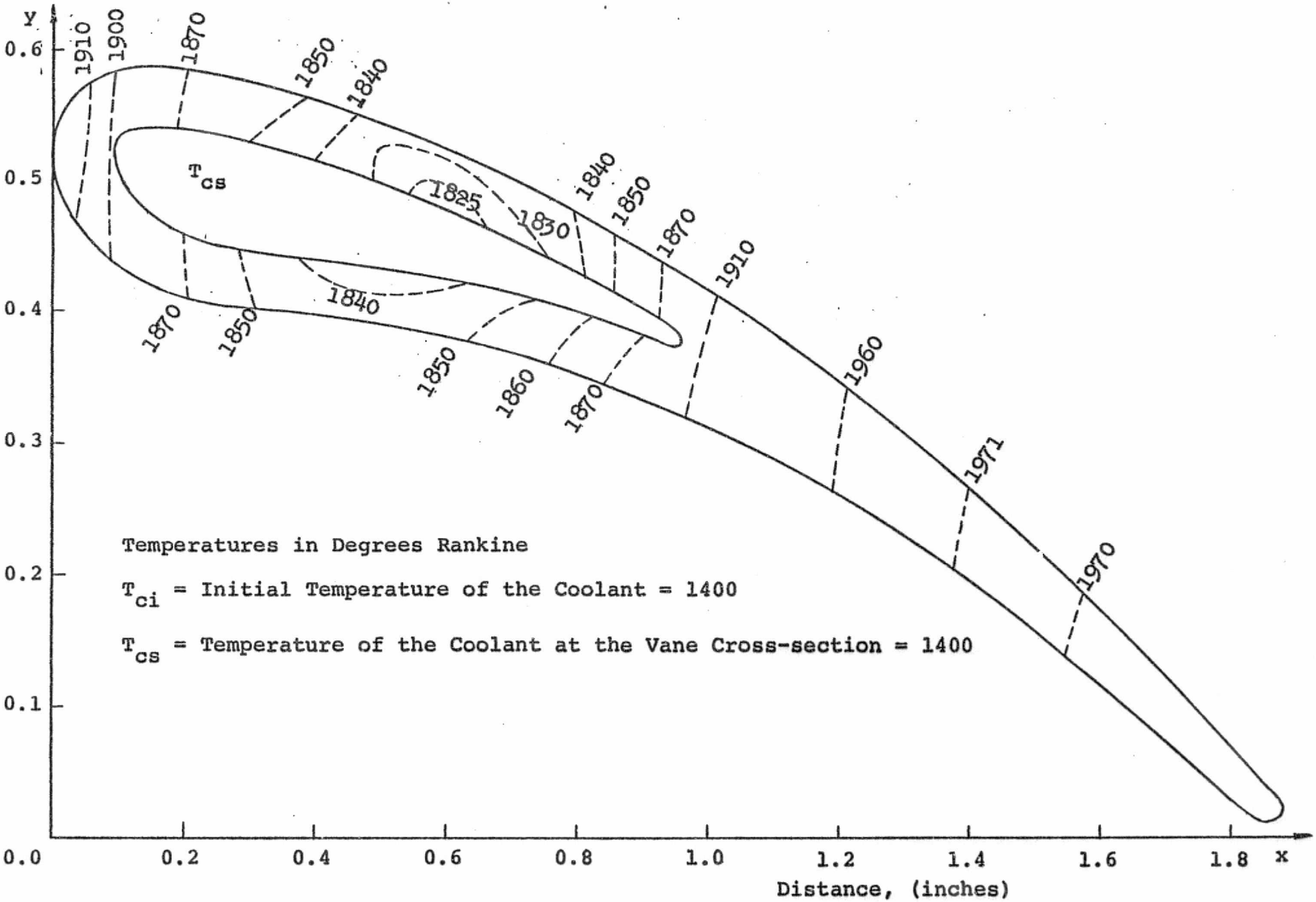

FIGURE 9 NOZZLE VANE TEMPERATURE DISTRIBUTION WITH 3% COOLANT

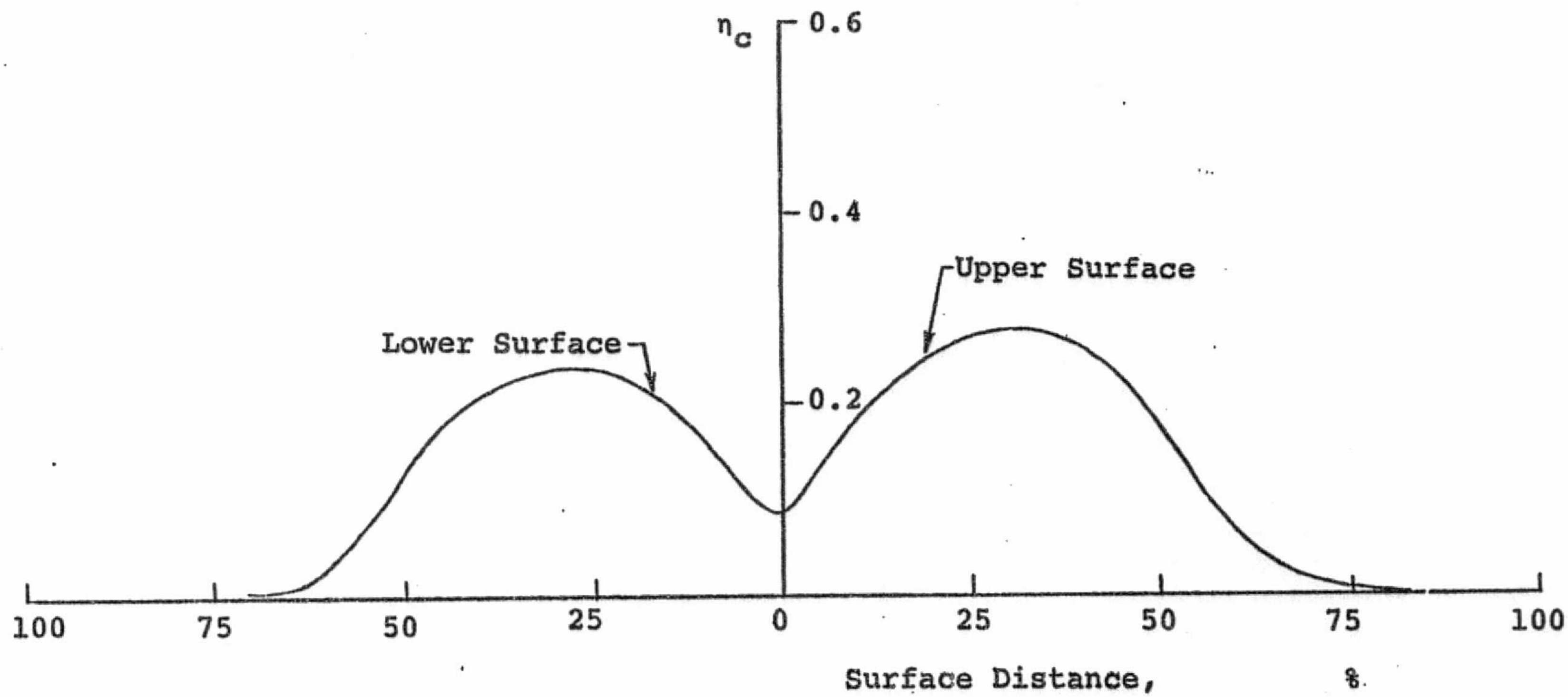

FIGURE 10. EFFECTIVENESS OF COOLING ON BLADE SURFACES WITH 3% COOLANT

APPENDIX A

PROGRAM INPUT

This computer program is an extension of the solid blade program of Reference 1. The blade is drawn in the grid network such that there are no multiple intersection points, i.e. each grid line has no more than two intersections with the outer boundary. The blade also has to be drawn, such that I = 1 line is tangential to the blade.

In order to read the coordinates of the boundary points at the grid line intersections, they are numbered in a counter-clockwise direction starting from any arbiterary point of intersection on the boundary as shown in Figure 7. In this figure the numbering is shown only for the outer boundary; a similar procedure can be followed for the inner boundary points. In case a vertical and a horizontal grid line intersect with the boundary at the same point, that point is given only one number.

Input for the computer program:

The input to the program consists of four main parts:

1. Physical parameters for the grid system and the blade.
2. Blade outer and inner boundary points.
3. Blade surface gas temperature and cooling air temperature.
4. Heat transfer coefficients on the outer and the inner boundary surfaces.

The first part of the input consists of the following items: DX, DY, XK, OME, SUMM, NX, NY, N1, N2, N3, N4, IMAX, NTE, NXO, NXI. These items are specified according to the format 5F5.3, 6I2, 4I3, and are explained below:

DX: The grid spacing in the x-direction (inches).

DY: The grid spacing in the y-direction (inches).

XK: Thermal conductivity of the blade material (Btu/hr.in.°F).

OME: Relaxation factor (If not known, use the value 1.0).

NX: The total number of mesh lines in x-direction ($\leq$ 40).

NY: The total number of mesh lines in y-direction ($\leq$ 25).

N1, N2 I mesh lines enclosing the blade inner hole without intersecting it; see Figure 7. In case of solid blade put N1 = N2 = NX.

N3, N4: J mesh lines enclosing the blade inner hole without intersecting it. In case of solid blade put N3 = N4 = NY.

IMAX: Maximum number of iterations allowed.

NTE: Number of iterations after which a print out of the results is required.

NXO: Total number of mesh lines intersections with the outer boundary. ($\leq$ 120).

NXI: Total number of mesh lines intersections with the inner boundary. ($\leq$ 120).

The second part of the input read in the blade inner and outer boundary coordinates. The Y1(I) array, corresponding to Y coordinates of the intersections of the I mesh lines with the lower surface of outer boundary are read according to 12F6.3 FORMAT. The next set is IP(I) point numbers (which are the sequence numbers for Y1(I) points), these are read according to 20I4 FORMAT. Similar values are read for upper surface of outer boundary, namely Y2(I) and IP(I). Then the X1(J) arrays, corresponding to the X coordinates of the points of intersection of the outer J mesh lines with the outer boundary (12F6.3). The next set is IP(J) numbers corresponding to these points. The arrays X2(J), IP(J) correspond to the second intersections of J lines with the outer boundary. All the previous coordinate sets are for the outer boundary. The inner boundary coordinates are defined in a similar manner as follows:

Y3(I), IP(I) Lower surface of inner boundary

Y4(I), IP(I) Upper surface of inner boundary

X3(J), IP(J) Near surface of inner boundary (first intersection)

X4(J), IP(J) Farther surface of inner boundary (second intersection)

In case of a solid blade N1 = N2 and N3 = N4, this last input part should be omitted.

The third part of the input specifies the surface gas temperatures (°R) in the following order:

TG(I,1): Gas temperature at the intersection points of the I mesh line with the lower surface of the outer blade boundary.

TG(I,2): Gas temperature at the intersection points of the I mesh lines with the upper surface of the outer blade boundary.

TGX(1,J): Gas temperature at the first intersection points of the J mesh lines with the surface of the blade outer boundary.

TGX(2,J): Gas temperature at the second intersection points of the J mesh lines with the surface of the blade outer boundary.

The gas temperature distribution on the inner boundary are defined in a similar way:

TG(I,3) Lower surface of inner boundary.

TG(I,4) Upper surface of inner boundary.

TGX(3,J) Near surface of inner boundary.

TGX(4,J) Far surface of inner boundary.

The fourth part of the input specifies the heat transfer coefficients (Btu/hr.in^2°F) in a similar order as the temperature input:

H(I,1) Lower surface of outer boundary.

H(I,2) Upper surface of outer boundary.

HX(1,J) Near surface of outer boundary.

HX(2,J) Far surface of outer boundary.

H(I,3) Lower surface of inner boundary.

H(I,4) Upper surface of inner boundary.

HX(3,J) Near surface of inner boundary.

HX(4,J) Far surface of inner boundary.

INPUT DATA

BLADE BOUNDARY POINTS COORDINATES

OUTER BOUNDARY			INNER BOUNDARY		
PT.NO.	X	Y	PT.NO.	X	Y
1	0.0	0.525000	1	0.093000	0.525000
2	0.007000	0.500000	2	0.100000	0.500000
3	0.024000	0.475000	3	0.110000	0.475000
4	0.050000	0.458000	4	0.150000	0.458000
5	0.062000	0.450000	5	0.153000	0.450000
6	0.100000	0.433000	6	0.200000	0.433000
7	0.126000	0.425000	7	0.250000	0.425000
8	0.150000	0.420000	8	0.290000	0.420000
9	0.200000	0.410000	9	0.300000	0.410000
10	0.250000	0.407000	10	0.350000	0.407000
11	0.300000	0.405000	11	0.400000	0.405000
12	0.350000	0.401000	12	0.450000	0.401000
13	0.360000	0.400000	13	0.500000	0.400000
14	0.400000	0.398000	14	0.550000	0.398000
15	0.450000	0.394000	15	0.600000	0.394000
16	0.500000	0.389000	16	0.613000	0.389000
17	0.550000	0.384000	17	0.650000	0.384000
18	0.600000	0.380000	18	0.700000	0.380000
19	0.637000	0.375000	19	0.750000	0.375000
20	0.650000	0.373000	20	0.800000	0.373000
21	0.700000	0.368000	21	0.808000	0.368000
22	0.750000	0.361000	22	0.850000	0.361000
23	0.800000	0.353000	23	0.900000	0.353000
24	0.825000	0.350000	24	0.925000	0.350000
25	0.850000	0.344000	25	0.950000	0.344000
26	0.900000	0.334000	26	0.958000	0.334000
27	0.945000	0.325000	27	0.950000	0.325000
28	0.950000	0.324000	28	0.912000	0.324000
29	1.000000	0.312000	29	0.900000	0.312000
30	1.049999	0.302000	30	0.850000	0.302000
31	1.056999	0.300000	31	0.834000	0.300000
32	1.099999	0.290000	32	0.800000	0.290000
33	1.150000	0.278000	33	0.750000	0.278000
34	1.160000	0.275000	34	0.739000	0.275000
35	1.200000	0.264000	35	0.700000	0.264000
36	1.245000	0.250000	36	0.650000	0.250000
37	1.249999	0.248000	37	0.617000	0.248000
38	1.299999	0.231000	38	0.600000	0.231000
39	1.316999	0.225000	39	0.550000	0.225000
40	1.349999	0.213000	40	0.500000	0.213000
41	1.388000	0.200000	41	0.489000	0.200000
42	1.403000	0.195000	42	0.450000	0.195000
43	1.450000	0.178000	43	0.400000	0.178000
44	1.454000	0.175000	44	0.350000	0.175000
45	1.499999	0.158000	45	0.330000	0.158000
46	1.521999	0.150000	46	0.300000	0.150000
47	1.549999	0.139000	47	0.250000	0.139000
48	1.582000	0.125000	48	0.200000	0.125000
49	1.599999	0.119000	49	0.150000	0.119000
50	1.641999	0.100000	50	0.100000	0.100000
51	1.650000	0.097000			
52	1.700000	0.075000			
53	1.749999	0.054000			
54	1.759999	0.050000			
55	1.799999	0.031000			
56	1.816000	0.025000			
57	1.849999	0.009000			
58	1.870000	0.025000			
59	1.849999	0.045000			
60	1.841999	0.050000			
61	1.799999	0.072000			
62	1.796000	0.075000			
63	1.750000	0.100000			
64	1.700000	0.125000			
65	1.650000	0.150000			
66	1.599999	0.175000			
67	1.549999	0.200000			
68	1.499999	0.223000			
69	1.495000	0.225000			
70	1.450000	0.247000			
71	1.443000	0.250000			
72	1.400000	0.270000			
73	1.388000	0.275000			
74	1.349999	0.291000			
75	1.327000	0.300000			
76	1.299999	0.311000			
77	1.264000	0.325000			
78	1.249999	0.330000			
79	1.200000	0.349000			
80	1.195999	0.350000			
81	1.150000	0.364000			
82	1.123999	0.375000			
83	1.099999	0.381000			
84	1.049999	0.400000			
85	1.000000	0.417000			
86	0.974000	0.425000			
87	0.950000	0.431000			
88	0.900000	0.448000			
89	0.892000	0.450000			
90	0.850000	0.462000			
91	0.810000	0.475000			
92	0.800000	0.479000			
93	0.750000	0.493000			
94	0.717000	0.500000			
95	0.700000	0.504000			
96	0.650000	0.515000			
97	0.600000	0.525000			
98	0.550000	0.535000			
99	0.500000	0.544000			
100	0.475000	0.550000			
101	0.450000	0.555000			
102	0.400000	0.565000			
103	0.350000	0.572000			
104	0.325000	0.575000			
105	0.300000	0.579000			
106	0.250000	0.582000			
107	0.200000	0.588000			
108	0.150000	0.585000			
109	0.100000	0.568000			
110	0.050000	0.582000			
111	0.035000	0.575000			
112	0.004000	0.550000			

```
DX = 0.05000       DY = 0.02500       OMEGA= 1.60000       THRM.COND.= 1.00000
NX =       39      NY =        25     MAX.ERROR= 0.02000
N1 =        2      N2 =        21     N3 =         15      N4 =         23
NXO =     112       NXI =      50
```

INPUT DATA

GAS TEMPERATURE DISTRIBUTION ON THE BLADE INNER AND OUTER SURFACE

```
    BOUNDARY POINTS ON I-LINES FOR LOWER SURFACE  OF     CUTER BOUNDRY
      (START FROM I= 2   TO   I= 38 )

**  1969.50 1975.50 1975.10 1975.70 1976.70 1977.50 1978.20 1978.70 1978.90 1979.00 1979.00 1979.00 1978.80 1978.60 1978.20
    1977.60 1976.40 1975.30 1974.30 1973.45 1972.70 1972.00 1971.50 1971.20 1971.20 1971.00 1970.70 1969.90 1968.90 1968.40
    1968.00 1967.30 1966.50 1965.60 1964.70 1963.90 1963.20

    BOUNDARY POINTS ON I LINES FOR UPPER SURFACE  OF     CUTER BOUNDRY
      (START FROM I= 2   TO I= 38 )

**  1998.50 1998.50 1998.40 1998.30 1998.20 1998.10 1997.80 1997.20 1996.80 1996.60 1996.50 1996.50 1996.30 1996.10 1995.70
    1995.20 1994.90 1994.50 1994.00 1993.50 1992.50 1991.50 1990.00 1988.20 1986.50 1984.60 1982.70 1980.60 1978.50 1976.50
    1974.60 1972.90 1970.80 1969.00 1967.50 1965.50 1963.90

    BOUNDARY POINTS ON I LINES FOR LOWER SURFACE OF      INNER BOUNDARY
      (START FROM I=   3   TO   I= 20 )

    1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00
    1400.00 1400.00 1400.00

    BOUNDARY POINTS ON I LINES FOR UPPER SURFACE OF      INNER BOUNDARY
      (START FROM I=   3   TO   I= 20 )

    1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00
    1400.00 1400.00 1400.00

    BOUNDARY POINTS ON J LINES FOR NEARER SURFACE OF     OUTER BOUNDARY
      (START FROM J= 2   TO   J= 24 )

    1963.70 1 64.60 1965.60 1966.50 1967.60 1968.30 1968.80 1970.10 1970.90 1971.20 1971.40 1972.60 1974.50 1977.00 1978.90
    1978.30 197[illegible].00 1972.00 1965.60 2000.00 1999.00 1999.00 1998.50

    BOUNDARY POINTS ON J LINES FOR FARTHER SURFACE OF    CUTER BOUNDARY
      (START FROM J= 2   TO   J= 24 )

    1963.00 1964.20 1965.80 1967.50 1969.00 1970.80 1972.90 1974.60 1976.90 1979.00 1981.50 1984.00 1986.10 1988.60 1990.80
    1992.50 1993.80 1994.60 1995.10 1996.00 1996.50 1996.70 1998.10

    BOUNDARY POINTS UN J LINES FOR NEARER SURFACE OF   INNER BOUNDARY
      (START FROM J= 16   TO   J= 22 )

    1400.00 1400.00 1400.00 1400.60 1400.00 1400.00 1400.00

    BOUNDARY POINTS ON J LINES FOR FARTHER SURFACE OF  INNER BOUNDARY
      (START FROM J= 16   TO   J= 22 )

    1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00
```

INPUT DATA

HEAT COEFFICIENT DISTRIBUTION ON THE BLADE INNER AND OUTER SURFACE

BOUNDARY POINTS ON I-LINES FOR LOWER SURFACE OF OUTER BOUNDRY
(START FROM I= 2 TO I= 38)

**	1.34	0.86	0.96	0.99	1.00	1.01	1.00	1.02	1.05	1.08	1.12	1.17	1.22	1.28	1.37
	1.46	1.54	1.61	1.67	1.70	1.71	1.70	1.67	1.64	1.61	1.60	1.61	1.65	1.70	1.74
	1.74	1.75	1.75	1.75	1.76	1.79	1.45								

BOUNDARY POINTS ON I LINES FOR UPPER SURFACE OF OUTER BOUNDRY
(START FROM I= 2 TO I= 38)

**	2.16	1.29	0.82	0.92	0.99	1.10	1.10	1.04	0.96	0.86	0.78	0.74	0.76	0.82	0.98
	0.96	0.99	1.02	1.05	1.08	1.21	1.33	1.44	1.55	1.59	1.62	1.61	1.60	1.57	1.54
	1.49	1.44	1.40	1.34	1.28	1.21	1.13								

BOUNDARY POINTS ON I LINES FOR LOWER SURFACE OF INNER BOUNDARY
(START FROM I= 3 TO I= 20)

0.40	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.37	0.37	0.37	0.39	0.39	0.40	0.42
0.42	0.44	0.45												

BOUNDARY POINTS ON I LINES FOR UPPER SURFACE OF INNER BOUNDARY
(START FROM I= 3 TO I= 20)

0.40	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.37	0.37	0.37	0.39	0.39	0.40	0.42
0.42	0.44	0.45												

BOUNDARY POINTS ON J LINES FOR NEARER SURFACE OF OUTER BOUNDARY
(START FROM J= 2 TO J= 24)

1.79	1.76	1.75	1.75	1.75	1.74	1.70	1.64	1.61	1.62	1.67	1.71	1.66	1.50	1.20
1.00	0.93	1.10	1.70	2.29	2.55	2.50	2.29							

BOUNDARY POINTS ON J LINES FOR FARTHER SURFACE OF OUTER BOUNDARY
(START FROM J= 2 TO J= 24)

1.10	1.16	1.22	1.28	1.34	1.40	1.44	1.49	1.54	1.58	1.60	1.61	1.60	1.54	1.38
1.21	1.07	1.01	0.98	0.85	0.74	0.89	1.13							

BOUNDARY POINTS ON J LINES FOR NEARER SURFACE OF INNER BOUNDARY
(START FROM J= 16 TO J= 22)

0.44	0.42	0.37	0.36	0.36	0.40	0.40

BOUNDARY POINTS ON J LINES FOR FARTHER SURFACE OF INNER BOUNDARY
(START FROM J= 16 TO J= 22)

0.45	0.44	0.42	0.40	0.37	0.37	0.36

APPENDIX B

PROGRAM OUTPUT

The first part of the output serves as a check for the input data and the calculation procedures. The coordinates of the boundary points, through which a parabolic curve is fitted in the subroutine CURVE, are printed out together with the coefficients of the parabola. To distinguish between the boundary points on the interior and exterior blade surfaces, an integer I is assigned the value 0 in the first case and 1 in the second case. To monitor the convergence process the sum of the difference square between two successive iterations values at all the grid points is also printed. The second part of the output deals with the temperature distribution after the final iteration. The temperature at all the grid points, including the fictitious points which lie outside the region of calculations, are printed out. Next, the temperature at the interior points of the blade are listed after eliminating the fictitious points at which the temperatures are constant and equal to the initialized temperature value. Temperature distribution on the boundary points are also given in the output as well as the coordinates of the isothermal lines.

SUBROUTINE CURVE -OUTPUT-

I=0,OUTER BOUNDARY. I=1,INNER BOUNDARY
IP BOUNDARY POINT NUMBER

(B2,C2) IS THE POINT ON THE BOUNDARY. (B1,C1) AND (B3,C3) ARE THE SURROUNDING POINTS ON BLADE. A,B,C, ARE THE COEFS
OF THE PARBOLIC CURVE Y=A+B*X+C*X*X

I	IP	B1	C1	B2	C2	B3	C3	A	B	C
0	4	0.02400	0.47500	0.05000	0.45800	0.06700	0.45000	0.49029	-0.62809	-0.33778
0	110	0.10000	0.58800	0.05000	0.58200	0.03500	0.57500	0.54933	0.41997	-5.33331
0	6	0.06200	0.45000	0.10000	0.43300	0.12600	0.42500	0.49127	-0.80087	2.18237
1	2	0.09300	0.52500	0.10000	0.50600	0.11000	0.50000	1.91177	-26.71048	124.34428
1	50	0.15000	0.54200	0.10000	0.53800	0.09100	0.52500	0.06233	7.87470	-31.17912
0	109	0.15000	0.58900	0.10000	0.58900	0.05030	0.58200	0.57100	0.27001	-1.00011
0	8	0.12600	0.42500	0.15000	0.42000	0.20000	0.41000	0.45338	-0.23941	0.11326
1	4	0.11000	0.50000	0.15000	0.47800	0.15100	0.47500	0.38783	2.17092	-10.45898
1	49	0.20000	0.54000	0.15300	0.54200	0.10000	0.53800	0.51200	0.37999	-1.20006
0	108	0.20000	0.58900	0.15000	0.58900	0.10000	0.58800	0.58000	0.11998	-0.39990
0	9	0.15000	0.42000	0.20000	0.41000	0.25000	0.40703	0.49200	-0.68997	1.40016
1	6	0.15300	0.47500	0.20000	0.46000	0.25000	0.45300	0.54034	-0.97109	1.84684
1	48	0.25000	0.53600	0.20000	0.54000	0.15000	0.54200	0.53600	0.05999	-0.39982
0	107	0.25000	0.58200	0.20000	0.58900	0.15000	0.58900	0.56700	0.33000	-0.99991
0	10	0.20000	0.41000	0.25000	0.40700	0.30000	0.40500	0.43290	-0.15000	0.20004
1	7	0.20000	0.46000	0.25000	0.45300	0.28000	0.45000	0.51300	-0.36499	0.50019
1	47	0.30000	0.51000	0.25000	0.53600	0.20000	0.54030	0.53600	0.10000	-0.39983
0	106	0.30000	0.57900	0.25000	0.58200	0.20000	0.58800	0.64200	-0.39001	0.59987
0	11	0.25900	0.40700	0.30000	0.40500	0.35000	0.40100	0.38700	0.18000	-0.40006
1	9	0.28000	0.45000	0.30000	0.44900	0.35030	0.44500	0.42800	0.19849	-0.42827
1	46	0.33000	0.52500	0.30000	0.53000	0.25000	0.53600	0.52225	0.20082	-0.58312
0	105	0.32500	0.57500	0.30000	0.57900	0.25000	0.58200	0.49700	0.67334	-1.33317
0	12	0.30000	0.40500	0.35030	0.40100	0.36000	0.40000	0.39400	0.13660	-0.33379
1	10	0.30000	0.44900	0.35000	0.44500	0.40000	0.44200	0.49401	-0.20593	0.19980
1	44	0.40000	0.51500	0.35000	0.52200	0.33000	0.52500	0.59102	-0.24715	0.14220
0	103	0.40000	0.56500	0.35300	0.57200	0.32500	0.57500	0.58368	0.06000	-0.26639
0	14	0.36000	0.40000	0.40000	0.39800	0.45000	0.39400	0.37001	0.20361	-0.33317
1	11	0.35000	0.44500	0.40000	0.44200	0.45030	0.43900	0.46600	-0.06001	-0.00026
1	43	0.45000	0.50800	0.40000	0.51500	0.35030	0.52200	0.57100	-0.13983	-0.00024
0	102	0.45000	0.55500	0.40000	0.56500	0.35300	0.57200	0.53701	0.30996	-0.59990
0	15	0.40000	0.39800	0.45000	0.39400	0.50000	0.38500	0.39400	0.09031	-0.19986
1	12	0.40000	0.44200	0.45000	0.43900	0.50000	0.43500	0.43000	0.10995	-0.20010
1	42	0.48900	0.50000	0.45030	0.50830	0.40000	0.51500	0.43926	0.48231	-0.73239
0	101	0.47500	[illegible]	0.45000	0.55500	0.40000	0.56500	0.64508	-0.20038	0.0
0	16	0.45000	[illegible]	0.50000	0.39900	0.55000	0.38400	0.43099	-0.05990	-0.00024
1	13	0.45300	0.43900	0.50000	0.43500	0.55000	0.43100	0.47499	-0.08035	-0.00024
1	40	0.55000	0.48800	0.50000	0.49800	0.48900	0.50000	0.51596	0.11348	-0.29787
0	99	0.55000	0.53530	0.50000	0.54400	0.47500	0.55030	0.85417	-1.02036	0.80025
0	17	0.50000	0.38900	0.55000	0.38400	0.60000	0.38000	0.49399	-0.31021	0.15981
1	14	0.50000	0.43500	0.55000	0.43100	0.60030	0.42600	0.41999	0.12995	-0.20005
1	39	0.60000	0.47900	0.55000	0.48300	0.50030	0.45830	0.65302	-0.40937	0.20005
0	98	0.60000	0.52500	0.55000	0.53500	0.50000	0.54400	0.57900	0.03004	-0.20005
0	18	0.55000	0.38400	0.60000	0.38000	0.63700	0.37500	0.21889	0.64828	-0.63347
1	15	0.55000	0.43100	0.60000	0.42600	0.61300	0.42500	0.60714	-0.52187	0.36735
1	38	0.61700	0.47500	0.60000	0.47500	0.55000	0.48300	0.31475	0.76883	-0.82531
0	97	0.65000	0.51500	0.60000	0.52500	0.55000	0.53500	0.64496	-0.20000	0.00024
0	20	0.63700	0.37500	0.65000	0.37300	0.70030	0.36800	0.82618	-1.25291	0.85320
1	17	5.80000	1.74000	0.65000	0.42100	0.70000	0.41500	0.53256	-0.21957	0.07375
1	36	0.70300	0.45700	0.65030	0.46900	0.61700	0.47500	0.33600	0.70614	-0.70135
0	96	0.70300	0.50400	0.65000	0.51500	0.60000	0.52500	0.56699	0.05007	-0.20005
0	21	0.65000	0.37300	0.70000	0.36800	0.75000	0.36100	0.25595	0.44002	-0.39995
1	18	0.65000	0.42100	0.70000	0.41500	0.75000	0.40900	0.49900	-0.11996	0.0
1	35	0.71900	0.45000	0.70000	0.45700	0.65000	0.46900	0.53462	-1.15076	0.68007
0	95	0.71900	0.50000	0.70000	0.50400	0.65030	0.51500	0.72060	-0.40491	0.13831
0	22	0.73000	0.36200	0.75000	0.36100	0.80000	0.35300	0.36100	0.15001	-0.19986
1	19	0.70000	0.41500	0.75000	0.40900	0.80000	0.40200	0.39398	0.17005	-0.20010
1	33	0.80000	0.43500	0.75000	0.44700	0.73900	0.45000	0.94971	-1.07295	0.53737
0	93	0.80000	0.47900	0.75000	0.49300	0.71900	0.50000	0.30152	0.75689	-0.66904
0	23	0.75000	0.36100	0.80000	0.35300	0.82500	0.35000	0.80094	-0.98665	0.53338
1	20	0.75000	0.40900	0.80000	0.40200	0.80800	0.40000	-0.62416	2.79949	-1.89974
1	32	0.83400	0.42500	0.80000	0.43500	0.75000	0.44700	0.24040	0.75866	-0.64426
0	92	0.81000	0.47500	0.80000	0.47900	0.75000	0.45100	-0.49953	2.82868	-2.00598
0	25	0.82500	0.35000	0.85000	0.34400	0.90000	0.33400	0.72196	-1.13350	0.53338
1	22	0.80800	0.40000	0.85900	0.39200	0.90000	0.38200	0.48292	-0.01944	-0.10367
1	30	0.90000	0.40500	0.85000	0.42000	0.83400	0.42500	0.01933	-0.61021	0.18940
0	90	0.89200	0.45000	0.85000	0.46200	0.81000	0.47500	1.06818	-1.12029	0.47945
0	26	0.85000	0.34400	0.90000	0.33400	0.94500	0.32500	0.51400	-0.19996	0.0
1	23	0.85300	0.39200	0.90300	0.38200	0.92500	0.37500	-0.25393	1.66561	-1.06739
1	29	0.91200	0.40000	0.90000	0.40500	0.85000	0.42000	-0.76290	2.98890	-1.88000
0	88	0.95000	0.43100	0.90000	0.44800	0.89200	0.45000	-0.57326	2.53213	-1.55013
0	28	0.94500	0.32500	0.95000	0.32400	1.00000	0.31200	-0.14035	1.10261	-0.72136
1	25	0.92500	0.37500	0.95000	0.37100	0.95000	0.37500	18.05461	-37.56757	19.94594
1	27	0.95800	0.37500	0.95000	0.38000	0.91230	0.40003	-24.01452	52.91624	-28.53845
0	87	0.97400	0.42500	0.95000	0.43100	0.90000	0.44800	1.79167	-2.58993	1.21611
0	29	0.95000	0.32400	1.00000	0.31200	1.05000	0.30700	0.93153	-1.01906	0.39981
0	85	1.05700	0.40000	1.00000	0.41700	0.97400	0.42500	0.31100	0.52973	-0.42282
0	30	1.00000	0.31200	1.05000	0.30200	1.05700	0.30000	-1.05176	2.87202	-1.49702
0	85	1.10000	0.38100	1.05000	0.40000	1.00000	0.41700	0.33705	0.48020	-0.40005
0	32	1.05700	0.30000	1.10000	0.29000	1.15000	0.27800	0.45751	-0.05957	-0.08006
0	83	1.12100	0.37500	1.10000	0.38100	1.05000	0.40000	2.11716	-3.24197	1.33093
0	33	1.10000	0.29000	1.15000	0.27800	1.16000	0.27500	-0.72568	2.03831	-1.01411
0	81	1.19600	0.35000	1.15000	0.36400	1.12100	0.37500	2.00716	-2.64702	0.99021
0	35	1.16000	0.27500	1.20000	0.26400	1.24500	0.25000	0.00195	0.72969	-0.42578
0	79	1.25000	0.33000	1.20000	0.34900	1.19600	0.35000	-2.09950	5.67614	-2.47727
0	37	1.24500	0.25000	1.25000	0.24800	1.30000	0.23100	2.72864	-2.81250	0.98024
0	78	1.26400	0.32500	1.25000	0.33000	1.20000	0.34900	1.31966	-1.21047	0.35156

I	IP	B1	C1	B2	C2	B3	C3	A	B	C
0	38	1.25000	0.24800	1.30000	0.23100	1.31700	0.22500	0.35833	0.15312	-0.15062
0	74	1.32700	0.30000	1.30000	0.31100	1.26400	0.32500	0.33374	0.36523	-0.29395
0	40	1.31700	0.22500	1.35000	0.21300	1.38800	0.20000	1.24689	-1.17742	0.30444
0	76	1.30800	0.27500	1.35900	0.29100	1.32700	0.30000	-0.06016	0.92841	-0.49545
0	42	1.38800	0.20000	1.40000	0.19500	1.45000	0.17800	3.10732	-3.76719	1.20469
0	72	1.44300	0.25000	1.47300	0.27000	1.38800	0.27500	-0.84972	2.07292	-0.87292
0	43	1.40000	0.19500	1.45000	0.17800	1.45400	0.17500	-13.50397	20.10938	-7.16667
0	70	1.49500	0.22500	1.45000	0.24700	1.44300	0.25000	-1.57744	2.95588	-1.17279
0	45	1.45400	0.17500	1.50000	0.15800	1.52200	0.15000	0.91467	-0.63732	0.08803
0	68	1.55000	0.20000	1.50000	0.22300	1.49500	0.22500	-1.67494	2.94643	-1.11607
0	47	1.57200	0.15000	1.55000	0.13900	1.58200	0.12500	-0.99479	1.87281	-0.73575
0	67	1.60000	0.17500	1.55000	0.20000	1.50000	0.22300	-0.01718	0.76026	-0.40005
0	49	1.58200	0.12500	1.60000	0.11900	1.64200	0.10000	-4.32879	5.92578	-1.96615
0	66	1.65000	0.15000	1.60000	0.17500	1.55000	0.20000	0.97857	-0.50216	0.0
0	51	1.64200	0.10000	1.65000	0.09700	1.70000	0.07500	-2.35298	3.35677	-1.13542
0	65	1.70000	0.12500	1.65000	0.15000	1.60000	0.17500	0.97860	-0.50216	0.0
0	52	1.65000	0.09700	1.70000	0.07500	1.75000	0.05400	1.38453	-1.11021	0.20014
0	64	1.75000	0.10000	1.70000	0.12500	1.65000	0.15000	0.97562	-0.50048	0.0
0	53	1.70000	0.07500	1.75000	0.05400	1.76000	0.05000	1.80798	-1.59274	0.33871
0	63	1.79600	0.07500	1.75000	0.10000	1.70000	0.12500	-0.37317	1.06439	-0.45373
0	55	1.76000	0.05000	1.80000	0.03100	1.81600	0.02500	6.83010	-7.13368	1.86556
0	61	1.84200	0.05900	1.90300	0.07300	1.79600	0.07500	-2.40332	3.25000	-1.04688
0	57	1.81600	0.02500	1.85000	0.00900	1.87000	0.02500	80.98793	-87.07910	23.84128
0	59	1.87000	0.02500	1.85000	0.04500	1.84200	0.05000	-41.75995	45.87500	-12.57969
0	56	1.80000	0.03100	1.81600	0.02500	1.85000	0.00900	-5.64792	6.66197	-1.94810
0	58	1.85000	0.00900	1.87000	0.02500	1.95000	0.04500	100.00000	100.00000	100.00000
0	54	1.75000	0.05400	1.76000	0.05000	1.80000	0.03100	-4.05724	5.10312	-1.57168
0	60	1.85000	0.04500	1.84200	0.05000	1.80000	0.07300	-3.98028	4.97569	-1.51389
0	52	1.65000	0.09700	1.70000	0.07500	1.75000	0.05400	1.39451	-1.11021	0.20014
0	62	1.80000	0.07300	1.79650	0.07503	1.75000	0.10000	4.04959	-3.88889	0.93056
0	50	1.60000	0.11900	1.64200	0.10000	1.65000	0.05700	4.80599	-5.35764	1.51389
0	63	1.79600	0.07500	1.75000	0.10000	1.70000	0.12500	-0.37404	1.06521	-0.45400
0	48	1.55000	0.13900	1.50200	0.12500	1.60000	0.11900	-5.77520	-6.77822	2.03024
0	64	1.75000	0.10000	1.70000	0.12500	1.65000	0.15000	0.97570	-0.50072	0.0
0	46	1.53000	0.15800	1.52200	0.15000	1.55000	0.13905	-0.61411	1.37311	-0.57386
0	65	1.70000	0.12500	1.65000	0.15000	1.60000	0.17500	0.97860	-0.50216	0.0
0	44	1.45000	0.17800	1.45400	0.17500	1.50000	0.15890	18.54001	-24.48610	8.15278
0	66	1.65000	0.15000	1.60000	0.17500	1.55000	0.20000	0.97857	-0.50216	0.0
0	41	1.35000	0.21300	1.38800	0.20000	1.40000	0.15500	-2.11051	3.72517	-1.48438
0	67	1.60000	0.17500	1.55000	0.20000	1.50000	0.22300	-0.01718	0.76026	-0.40005
0	39	1.30000	0.23100	1.31700	0.22500	1.35000	0.21300	0.32543	0.21121	-0.21552
0	69	1.50300	0.22300	1.49500	0.22500	1.45000	0.24700	5.13745	-6.13636	-1.91477
0	36	1.20000	0.26400	1.24500	0.25000	1.25000	0.24800	-1.98014	3.97396	-1.74479
0	71	1.45000	0.24700	1.44300	0.25000	1.40000	0.27000	2.50963	-2.67917	0.76667
0	34	1.15000	0.27800	1.16000	0.27500	1.20000	0.26400	1.33924	-1.52500	0.52500
0	73	1.40000	0.27000	1.39800	0.27500	1.35000	0.29100	1.02083	-0.65625	0.08594
0	31	1.05000	0.30200	1.05700	0.30300	1.10000	0.29000	1.76195	-2.48878	1.05469
0	75	1.35000	0.29100	1.32700	0.30000	1.30000	0.31100	1.41553	-1.27734	0.32813
0	21	0.90000	0.33400	0.94500	0.32500	0.95000	0.32400	0.51604	-0.20856	0.01070
0	77	1.30000	0.31130	1.26400	0.32500	1.25000	0.33000	-0.25937	1.31000	-0.67000
0	24	0.90000	0.35300	0.82500	0.35000	0.85000	0.34400	-1.13585	3.78053	-2.40267
0	80	1.20000	0.34900	1.19600	0.35000	1.15000	0.36400	2.34313	-3.06944	1.17361
0	19	0.60000	0.39300	0.63700	0.37500	0.65000	0.37300	0.31822	0.32921	-0.37624
1	24	0.90000	0.38200	0.92500	0.37500	0.95000	[illegible]	2.63323	-4.66221	2.40076
1	26	0.95000	0.37100	0.95600	0.37500	0.95100	0.38000	100.00000	100.00000	100.00000
0	82	1.15000	0.36400	1.12100	0.37500	1.10000	0.38100	-1.60389	3.86328	-1.86914
0	13	0.35000	0.40100	0.36000	0.40000	0.40000	0.39000	0.56196	-0.80875	0.99814
1	21	0.80000	0.40200	0.80000	0.40000	0.85000	0.35200	1.37442	-2.17438	1.19217
1	28	0.95000	0.38800	0.91200	0.40000	0.90000	0.40500	2.43081	-4.07853	2.01832
0	84	1.10000	0.38100	1.05000	0.40000	1.00000	0.41700	0.33734	0.48020	-0.40005
0	7	0.10000	0.43300	0.12600	0.42500	0.15000	0.42000	0.48081	-0.75688	1.98588
1	16	0.60000	0.42600	0.61300	0.42500	0.65000	0.42100	0.24261	0.68238	-0.62283
1	31	0.85000	0.42000	0.83400	0.42500	0.80000	0.43500	0.47497	0.30416	-0.36543
0	86	1.00000	0.41700	0.97400	0.42500	0.95000	0.43100	-0.34986	1.97132	-1.15487
0	5	0.05000	0.45800	0.06200	0.45000	0.10000	0.43300	0.50493	-1.15792	4.38601
1	8	0.25000	0.45300	0.28000	0.45000	0.10000	0.44900	0.54799	-0.63008	1.00335
1	34	0.75000	0.44700	0.73900	0.45000	0.70000	0.45700	-0.38158	2.50558	-1.86389
0	89	0.90000	0.44800	0.89200	0.45000	0.85000	0.46200	1.24878	-1.53381	0.71886
0	3	0.00700	0.50000	0.02400	0.47500	0.05000	0.45800	0.51348	-2.05941	18.99396
1	5	0.15000	0.47800	0.15300	0.47500	0.20000	0.46000	0.94062	-5.12738	13.62368
1	37	0.65000	0.46900	0.61700	0.47500	0.60000	0.47900	1.01189	-1.54043	1.07021
0	91	0.85000	0.46200	0.81000	0.47500	0.80000	0.47900	1.77332	-2.01791	1.50149
0	2	0.0	0.52500	0.00700	0.50000	0.02400	0.47500	0.52500	-4.18427	87.53522
1	3	0.10000	0.50600	0.11300	0.50000	0.15000	0.47800	0.57700	-0.80909	1.00156
1	41	0.50000	0.49800	0.48900	0.50000	0.45000	0.50500	0.70290	-0.64167	0.46111
0	94	0.75000	0.49300	0.71900	0.50000	0.70300	0.50400	0.49760	0.22065	-0.30567
0	1	0.00000	0.55000	0.0	0.52500	0.00700	0.50000	100.00000	100.00000	100.00000
1	1	0.10000	0.53800	0.09100	0.52500	0.10000	0.50600	100.00000	100.00000	100.00000
1	45	0.15000	0.52200	0.11000	0.52500	0.30000	0.51000	0.61100	-0.37651	0.33379
0	97	0.65000	0.51500	0.60000	0.52500	0.55000	0.51500	0.64496	-0.70000	0.0
0	112	0.03500	0.57500	0.00000	0.55000	0.0	0.52500	0.52500	1.62763	-62.83080
0	100	0.50000	0.54400	0.47500	0.55000	0.45000	0.55500	0.47396	0.54198	-0.79962
0	111	0.05000	0.58200	0.01500	0.57500	0.00800	0.55000	0.53951	1.19611	-10.93474
0	104	0.35000	0.51200	0.12500	0.57500	0.10000	0.57900	0.70499	-0.66003	0.80105

```
ITERATION=  1     ERROR= 0.68492E 04
ITERATION=  2     ERROR= 0.41211E 04
ITERATION=  3     ERROR= 0.43164E 04
ITERATION=  4     ERROR= 0.30796E 04
ITERATION=  5     ERROR= 0.28486E 04
ITERATION=  6     ERROR= 0.20878E 04
ITERATION=  7     ERROR= 0.18616E 04
ITERATION=  8     ERROR= 0.14249E 04
ITERATION=  9     ERROR= 0.12764E 04
ITERATION= 10     ERROR= 0.10312E 04
ITERATION= 11     ERROR= 0.90558E 03
ITERATION= 12     ERROR= 0.76408E 03
ITERATION= 13     ERROR= 0.67744E 03
ITERATION= 14     ERROR= 0.57998E 03
ITERATION= 15     ERROR= 0.51642E 03
ITERATION= 16     ERROR= 0.44972E 03
ITERATION= 17     ERROR= 0.40293E 03
ITERATION= 18     ERROR= 0.35433E 03
ITERATION= 19     ERROR= 0.32005E 03
ITERATION= 20     ERROR= 0.28368E 03
ITERATION= 21     ERROR= 0.25802E 03
ITERATION= 22     ERROR= 0.23027E 03
ITERATION= 23     ERROR= 0.21106E 03
ITERATION= 24     ERROR= 0.18911E 03
ITERATION= 25     ERROR= 0.17458E 03
ITERATION= 26     ERROR= 0.15723E 03
ITERATION= 27     ERROR= 0.14604E 03
ITERATION= 28     ERROR= 0.13184E 03
ITERATION= 29     ERROR= 0.12323E 03
ITERATION= 30     ERROR= 0.11153E 03
ITERATION= 31     ERROR= 0.10484E 03
ITERATION= 32     ERROR= 0.95047E 02
ITERATION= 33     ERROR= 0.89782E 02
ITERATION= 34     ERROR= 0.81429E 02
ITERATION= 35     ERROR= 0.77302E 02
ITERATION= 36     ERROR= 0.70290E 02
ITERATION= 37     ERROR= 0.66989E 02
ITERATION= 38     ERROR= 0.60911E 02
ITERATION= 39     ERROR= 0.58251E 02
ITERATION= 40     ERROR= 0.53029E 02
ITERATION= 41     ERROR= 0.50878E 02
ITERATION= 42     ERROR= 0.46335E 02
ITERATION= 43     ERROR= 0.44687E 02
ITERATION= 44     ERROR= 0.40737E 02
ITERATION= 45     ERROR= 0.39349E 02
ITERATION= 46     ERROR= 0.35846E 02
ITERATION= 47     ERROR= 0.34696E 02
ITERATION= 48     ERROR= 0.31599E 02
ITERATION= 49     ERROR= 0.30698E 02
ITERATION= 50     ERROR= 0.28027E 02
ITERATION= 51     ERROR= 0.27266E 02
ITERATION= 52     ERROR= 0.24844E 02
ITERATION= 53     ERROR= 0.24171E 02
ITERATION= 54     ERROR= 0.21986E 02
ITERATION= 55     ERROR= 0.21479E 02
ITERATION= 56     ERROR= 0.19517E 02
ITERATION= 57     ERROR= 0.19091E 02
ITERATION= 58     ERROR= 0.17388E 02
ITERATION= 59     ERROR= 0.17020E 02
ITERATION= 60     ERROR= 0.15485E 02
ITERATION= 61     ERROR= 0.15214E 02
ITERATION= 62     ERROR= 0.13880E 02
ITERATION= 63     ERROR= 0.13633E 02
ITERATION= 64     ERROR= 0.12395E 02
```

T-MATRIX,GIVES ALL INTERIOR POINTS.INITIAL SETTING OF T IS 1600.0
ONLY THOSE INSIDE BLADE ARE CHANGED AND WILL BE DIFFERENT FROM 1600.00

I \ J =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1918.97	1900.00	1900.00	1900.00
2	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1905.18	1906.78	1908.76	1910.70	1913.21	1900.00
3	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1893.23	1893.39	1893.21	1900.00	1899.69	1901.44	1900.00
4	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1883.12	1882.54	1882.90	1900.00	1900.00	1882.28	1885.50	1900.00
5	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1870.35	1868.13	1900.00	1900.00	1900.00	1870.52	1874.35	1900.00
6	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1859.20	1856.10	1900.00	1900.00	1900.00	1862.42	1866.42	1900.00
7	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1850.02	1900.00	1900.00	1900.00	1900.00	1856.64	1860.92	1900.00
8	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1844.31	1900.00	1900.00	1900.00	1847.40	1851.75	1900.00	1900.00
9	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1844.98	1841.40	1900.00	1900.00	1900.00	1842.91	1847.20	1900.00	1900.00
10	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1843.59	1839.87	1900.00	1900.00	1900.00	1838.50	1842.72	1900.00	1900.00
11	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1843.14	1839.27	1900.00	1900.00	1830.41	1834.58	1900.00	1900.00	1900.00
12	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1843.61	1839.64	1900.00	1900.00	1828.03	1831.80	1900.00	1900.00	1900.00
13	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1844.80	1840.76	1900.00	1900.00	1827.25	1830.46	1900.00	1900.00	1900.00
14	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1850.56	1846.32	1900.00	1900.00	1825.63	1829.07	1900.00	1900.00	1900.00	1900.00
15	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1853.14	1848.76	1900.00	1900.00	1829.81	1833.03	1900.00	1900.00	1900.00	1900.00
16	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1856.58	1851.94	1900.00	1832.41	1835.82	1900.00	1900.00	1900.00	1900.00	1900.00
17	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1860.96	1855.66	1900.00	1839.89	1842.57	1900.00	1900.00	1900.00	1900.00	1900.00
18	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1873.53	1868.20	1900.00	1847.97	1850.52	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00
19	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1900.00	1882.97										

TEMPERATURE DISTRIBUTION INSIDE THE BLADE AND ON ITS SURFACE

J=	
24	1916.14 1913.21 1901.44 1885.50 1874.35 1866.42 1860.92 1858.50
23	1918.14 1910.70 1899.69 1882.28 1870.52 1862.42 1856.64 1851.75 1847.20 1842.72 1840.51
22	1918.97 1908.76 1900.00 1900.00 1900.00 1900.00 1900.00 1847.40 1842.91 1838.50 1834.58 1831.80 1830.46
21	1917.24 1906.78 1893.21 1900.00 1900.00 1900.00 1900.00 1900.00 1900.00 1900.00 1830.41 1828.03 1827.25 1829.07 1833.03 1834.94
20	1910.70 1905.18 1893.39 1882.90 1900.00 1900.00 1900.00 1900.00 1900.00 1900.00 1900.00 1900.00 1900.00 1825.63 1829.81 1835.82 1842.57 1843.93
19	1901.02 1893.23 1882.54 1868.13 1856.10 1900.00 1900.00 1900.00 1900.00 1900.00 1900.00 1900.00 1900.00 1900.00 1832.41 1839.89 1850.52 1861.31
18	1888.38 1883.12 1870.35 1859.20 1850.02 1844.31 1841.40 1839.87 1839.27 1839.64 1840.76 1900.00 1900.00 1900.00 1900.00 1847.97 1861.77 1878.11 1889.19
17	1846.90 1844.98 1843.59 1843.14 1843.61 1844.80 1846.32 1848.76 1851.94 1855.66 1900.00 1900.00 1875.82 1906.53 1926.84
16	1849.94 1850.56 1853.14 1856.58 1860.96 1868.20 1877.05 1900.00 1911.04 1927.74 1941.12 1946.01
15	1869.34 1873.53 1882.97 1896.69 1914.09 192[illegible].46 1941.85 1951.74 1959.17
14	1899.77 1901.39 1917.64 1931.94 1943.20 1952.38 1959.50 1964.39 1965.59
13	1936.56 1945.07 1953.53 1959.87 1964.44 196[illegible]58 1968.92
12	1956.43 1960.68 1964.85 1967.61 1969.53 [illegible]70.53
11	1965.46 1965.62 1967.87 1969.49 1970.52 1971.02
10	1968.80 1969.59 1970.42 1970.81 1970.88
9	1970.37 1970.43 1970.66 1970.62 1970.37
8	1970.55 1970.43 1970.12 1969.67
7	1970.15 1969.91 1969.41 1968.75
6	1969.42 1969.19 1968.50 1967.73
5	1968.38 1968.26 1967.49 1966.72
4	1967.24 1966.50 1965.81
3	1966.12 1965.57 1965.09
2	1965.20 1964.95 1964.91

```
TEMPERATURE DISTRIBUTION ON THE BOUNDARY


     BOUNDARY POINTS ON I-LINES FOR LOWER SURFACE  OF     CUTER BOUNDRY
       (START FROM I= 2  TO  I= 38 )

**   1904.30 1893.20 1883.31 1871.49 1861.14 1852.41 1847.35 1845.26 1844.44 1844.77 1846.06 1847.97 1850.90 1854.34 1859.09
     1865.03 1874.76 1886.21 1901.57 1919.67 1934.89 1945.92 1954.99 1961.14 1965.67 1968.17 1969.68 1970.44 1970.57 1970.33
     1969.83 1969.14 1968.23 1967.24 1966.30 1965.43 1964.91

     BOUNDARY POINTS ON I LINES FOR UPPER SURFACE  OF     OUTER BOUNDRY
       (START FROM I= 2  TO I= 38 )

**   1914.05 1902.76 1886.78 1876.01 1867.42 1861.58 1855.51 1849.76 1843.55 1837.56 1833.21 1830.46 1830.87 1833.51 1838.16
     1842.99 1851.53 1863.30 1878.32 1904.94 1926.84 1941.04 1951.59 1959.68 1964.40 1967.63 1969.64 1970.69 1971.02 1970.84
     1970.37 1969.67 1968.75 1967.73 1966.72 1965.73 1964.93

     BOUNDARY POINTS ON I LINES FOR LOWER SURFACE OF      INNER BOUNDARY
       (START FROM I=  3  TO  I= 20 )

     1893.73 1882.77 1867.07 1855.68 1846.41 1841.28 1838.77 1837.69 1837.65 1838.66 1840.59 1842.59 1846.04 1850.22 1855.23
     1864.34 1875.22 1892.04

     BOUNDARY POINTS ON I LINES FOR UPPER SURFACE OF      INNER BOUNDARY
       (START FROM I=  3  TO  I= 20 )

     1899.42 1880.96 1868.74 1859.94 1853.05 1846.88 1841.19 1835.57 1830.07 1826.07 1824.05 1824.73 1827.20 1832.00 1837.90
     1847.41 1860.01 1873.27

     BOUNDARY POINTS ON J LINES FOR NEARER SURFACE OF     CUTER BOUNDARY
       (START FROM J= 2  TO  J= 24 )

     1965.20 1966.12 1967.24 1968.38 1969.42 1970.15 1970.55 1970.37 1968.80 1965.46 1956.43 1936.56 1899.77 1869.34 1849.94
     1846.90 1888.38 1901.02 1910.70 1917.24 1918.97 1918.14 1916.14

     BOUNDARY POINTS ON J LINES FOR FARTHER SURFACE OF    CUTER BOUNDARY
       (START FROM J= 2  TO  J= 24 )

     1964.91 1965.09 1965.81 1966.72 1967.73 1968.75 1969.67 1970.37 1970.88 1971.02 1970.53 1968.92 1965.59 1959.17 1946.01
     1926.84 1889.19 1861.31 1843.93 1834.94 1830.46 1840.51 1858.50

     BOUNDARY POINTS ON J LINES FOR NEARER SURFACE OF   INNER BOUNDARY
       (START FROM J= 16  TO  J= 22 )

     1882.88 1856.28 1841.03 1849.94 1882.58 1888.71 1900.16

     BOUNDARY POINTS ON J LINES FOR FARTHER SURFACE OF  INNER BOUNDARY
       (START FROM J= 16  TO  J= 22 )

     1901.56 1863.45 1843.87 1830.81 1824.05 1831.01 1849.23
```

ISOTHERMAL LINE LOCATIONS

I	J	T	T - 1	T - 2	FRAC
2	19	1905	1904.3030	1905.1763	0.7982
2	20	1906	1905.1763	1906.7817	0.5131
2	21	1907	1906.7817	1908.7649	0.1101
2	21	1908	1906.7817	1908.7649	0.6143
2	22	1909	1908.7649	1910.6960	0.1217
2	22	1910	1908.7649	1910.6960	0.6396
2	23	1911	1910.6960	1913.2085	0.1210
2	23	1912	1910.6960	1913.2085	0.5190
2	23	1913	1910.6960	1913.2085	0.9170
2	24	1914	1913.2085	1914.0481	0.9427
3	23	1900	1899.6877	1901.4368	0.1785
3	23	1901	1899.6877	1901.4368	0.7503
3	24	1901	1901.4368	1900.0000	0.3040
4	18	1883	1883.1194	1882.5437	0.2074
4	22	1881	1880.9595	1882.2837	0.0306
4	22	1882	1880.9595	1882.2837	0.7858
4	23	1883	1882.2837	1885.5039	0.2224
4	23	1884	1882.2837	1885.5039	0.5330
4	23	1885	1882.2837	1885.5039	0.8435
4	24	1886	1885.5039	1900.0000	0.0342
5	19	1868	1868.1252	1867.0676	0.1184
5	18	1869	1870.3477	1868.1252	0.6064
5	18	1870	1870.3477	1868.1252	0.1564
5	17	1871	1871.4866	1870.3477	0.4272
5	22	1869	1868.7393	1870.5227	0.1462
5	22	1870	1868.7393	1870.5227	0.7069
5	23	1871	1870.5227	1874.3472	0.1248
5	23	1872	1870.5227	1874.3472	0.3863
5	23	1873	1870.5227	1874.3472	0.6477
5	23	1874	1870.5227	1874.3472	0.9092
5	24	1875	1874.3472	1900.0000	0.0254
5	24	1876	1874.3472	1900.0000	0.0644
6	19	1856	1856.0977	1855.6829	0.2354
6	18	1857	1859.2043	1856.0977	0.7095
6	18	1858	1859.2043	1856.0977	0.3877
6	18	1859	1859.2043	1856.0977	0.0658
6	17	1860	1861.1382	1859.2043	0.5886
6	17	1861	1861.1382	1859.2043	0.0715
6	22	1860	1859.9358	1862.4224	0.0258
6	22	1861	1859.9358	1862.4224	0.4280
6	22	1862	1859.9358	1862.4224	0.8301
6	23	1863	1862.4224	1866.4153	0.1447
6	23	1864	1862.4224	1866.4153	0.3951
6	23	1865	1862.4224	1866.4153	0.6456
6	23	1866	1862.4224	1866.4153	0.8960
6	24	1867	1866.4153	1900.0000	0.0174
7	18	1847	1850.0190	1846.4099	0.8365
7	18	1848	1850.0190	1846.4099	0.5594
7	18	1849	1850.0190	1846.4099	0.2824
7	18	1850	1850.0190	1846.4099	0.0053
7	17	1851	1852.4138	1850.0190	0.5904
7	17	1852	1852.4138	1850.0190	0.1728
7	22	1854	1853.0510	1856.6367	0.2647
7	22	1855	1853.0510	1856.6367	0.5435
7	22	1856	1853.0510	1856.6367	0.8224
7	23	1857	1856.6367	1860.9160	0.0849
7	23	1858	1856.6367	1860.9160	0.3186
7	23	1859	1856.6367	1860.9160	0.5523
7	23	1860	1856.6367	1860.9160	0.7859
7	24	1861	1860.9160	1900.0000	0.0021
8	18	1842	1944.3081	1841.2798	0.7619
8	18	1843	1944.3081	1841.2798	0.4318

APPENDIX C

PROGRAM LISTING

```
      COMMON T(40,25),TB(40,4),TBX(4,25),TG(40,4),TGX(4,25),H(40,4),HX(4
     1,25),Y1(40),Y2(40),Y3(40),Y4(40),X1(25),X2(25),X3(25),X4(25),BX(12
     20),BY(120),BXI(120),BYI(120),IP(120)
      COMMON DX,DY,NX,NY,NXO,NXI,ITER,N1,N2,N3,N4
      READ(5,5) DX,DY,XK,CME,SUMM,NX,NY,N1,N2,N3,N4,IMAX,NTE,NXO,NXI
  5   FORMAT(5F5.3,6I2,4I3)
      NX1=NX-1
      NY1=NY-1
      N11=N1+1
       N21=N2-1
      N31=N3+1
      N41=N4-1
      DO 46 I=1,NX
      DO 46 J=1,NY
 46   T(I,J)=1600.
      DO 44 I=1,NX
         DO 44 J=1,4
 44   TB(I,J)=1600.
      DO 49 J=1,NY
      DO 49 I=1,4
 49   TBX(I,J)=1600.
C
C
C   READS IN BOUNDARY POINTS SET AND THE CORRESPONDING SEQUENCE NUMBERS
C    FOR THE BOUNDARY POINTS
C
C
      READ(5,10) (Y1(I),I=1,NX1)
   10 FORMAT((12F6.3))
      READ(5,11) (IP(I),I=1,NX1)
   11 FORMAT(20I4)
      DO 12 I=1,NX1
      X=FLOAT(I-1)*DX
      BX(IP(I))=X
 12   BY(IP(I))=Y1(I)
      READ(5,10) (Y2(I),I=1,NX1)
      READ(5,11) (IP(I),I=1,NX1)
      DO 16 I=1,NX1
      X=FLOAT(I-1)*DX
      BX(IP(I))=X
   16 BY(IP(I))=Y2(I)
      READ(5,10) (X1(J),J=1,NY1)
      READ(5,11) (IP(J),J=1,NY1)
      DO 20 J=1,NY1
      Y=FLOAT(J-1)*DY
      BX(IP(J))=X1(J)
   20 BY(IP(J))=Y
      READ(5,10) (X2(J),J=1,NY1)
      READ(5,11) (IP(J),J=1,NY1)
      DO 24 J=1,NY1
      Y=FLOAT(J-1)*DY
      BX(IP(J))=X2(J)
   24 BY(IP(J))=Y
```

```
      IF(N1.EQ.N2.AND.N3.EQ.N4) GO TO 80
      READ(5,10) (Y3(I),I=N11,N21)
      READ(5,11) (IP(I),I=N11,N21)
      DO 28 I=N11,N21
      X=FLOAT(I-1)*DX
      BXI(IP(I))=X
   28 BYI(IP(I))=Y3(I)
      READ(5,10) (Y4(I),I=N11,N21)
      READ(5,11) (IP(I),I=N11,N21)
      DO 32 I=N11,N21
      X=FLOAT(I-1)*DX
      BXI(IP(I))=X
   32 BYI(IP(I))=Y4(I)
      READ(5,10) (X3(J),J=N31,N41)
      READ(5,11) (IP(J),J=N31,N41)
      DO 36 J = N31,N41
      Y=FLOAT(J-1)*DY
      BXI(IP(J))=X3(J)
   36 BYI(IP(J))= Y
      READ(5,10) (X4(J),J=N31,N41)
      READ(5,11) (IP(J),J=N31,N41)
      DO 40 J=N31,N41
      Y=FLOAT(J-1)*DY
      BXI(IP(J))=X4(J)
   40 BYI(IP(J))=Y
   80 CONTINUE
C
C     READS IN GAS TEMPS AND THEN HEAT TRANSFER COEFFICIENTS
C
      READ(5,50)(TG(I,1),I=1,NX1)
      READ(5,50)(TG(I,2),I=1,NX1)
      IF(N1.EQ.N2) GO TO 82
      READ(5,50)(TG(I,3),I=N11,N21)
      READ(5,50)(TG(I,4),I=N11,N21)
   82 CONTINUE
   50 FORMAT(10F8.2)
      READ(5,50)(TGX(1,J),J=2,NY1)
      READ(5,50)(TGX(2,J),J=2,NY1)
      IF(N3.EQ.N4) GO TO 83
      READ(5,50)(TGX(3,J),J=N31,N41)
      READ(5,50)(TGX(4,J),J=N31,N41)
   83 CONTINUE
      READ(5,45)(H(I,1),I=1,NX1)
      READ(5,45)(H(I,2),I=1,NX1)
      IF(N1.EQ.N2) GO TO 84
      READ(5,45)(H(I,3),I=N11,N21)
      READ(5,45)(H(I,4),I=N11,N21)
   84 CONTINUE
   45 FORMAT(10F8.4)
      READ(5,45)(HX(1,J),J=2,NY1)
      READ(5,45)(HX(2,J),J=2,NY1)
      IF (N3.EQ.N4) GO TO 85
      READ(5,45)(HX(3,J),J=N31,N41)
```

```
      READ(5,45)(HX(4,J),J=N31,N41)
   85 CONTINUE
      ITER=1
      WRITE(6,86)
   86 FORMAT(//,25X,'INPUT DATA')
      WRITE(6,88)
   88 FORMAT(///,15X,'BLADE BOUNDARY POINTS COORDINATES'/////17X,'OUTER
     1 BOUNDARY',9X,'INNER BOUNDARY',//10X,'PT.NO.',5X,'X',9X,'Y',6X,
     2'PT.NO.',6X,'X',9X,'Y'/)
      NXI1=NXI+1
      WRITE(6,851)((I,BX(I),BY(I),I,BXI(I),BY(I)),I=1,NXI)
      WRITE(6,853)((I,BX(I),BY(I)),I=NXI1,NXO)
  851 FORMAT(9X,I6,2F10.6,I6,2F10.6)
  853 FORMAT(9X,I6,2F10.6)
      WRITE(6,561)
  561 FORMAT('1',//15X,'INPUT DATA'//15X,'GAS TEMPERATURE DISTRIBUTION
     1ON THE BLADE INNER AND OUTER SURFACE',//)
      WRITE(6,530)  NX1
       WRITE(6,525) (TG(I,1),I=1,NX1)
      WRITE(6,531) NX1
      WRITE(6,525) (TG(I,2),I=1,NX1)
      IF(N1.EQ.N2.AND.N3.EQ.N4) GO TO 98
      WRITE (6,532) N11,N21
       WRITE(6,526) (TG(I,3),I=N11,N21)
      WRITE(6,533) N11,N21
      WRITE(6,526) (TG(I,4),I=N11,N21)
   98 CONTINUE
      WRITE (6,534) NY1
      WRITE(6,526) (TGX(1,J),J=2,NY1)
      WRITE(6,535) NY1
      WRITE(6,526) (TGX(2,J),J=2,NY1)
      IF(N1.EQ.N2.AND.N3.EQ.N4) GO TO 96
      WRITE(6,536) N31,N41
      WRITE(6,526) (TGX(3,J),J=N31,N41)
      WRITE(6,537) N31,N41
      WRITE(6,526) (TGX(4,J),J=N31,N41)
      WRITE(6,401)
   96 CONTINUE
      WRITE(6,562)
  562 FORMAT('1',//15X,'INPUT DATA'//15X,'HEAT COEFFICIENT DISTRIBUTION
     1ON THE BLADE INNER AND OUTER SURFACE',//)
      WRITE(6,530)  NX1
       WRITE(6,525) ( H(I,1),I=1,NX1)
      WRITE(6,531) NX1
      WRITE(6,525) ( H(I,2),I=1,NX1)
      IF(N1.EQ.N2.AND.N3.EQ.N4) GO TO 97
      WRITE (6,532) N11,N21
       WRITE(6,526) ( H(I,3),I=N11,N21)
      WRITE(6,533) N11,N21
      WRITE(6,526) ( H(I,4),I=N11,N21)
   97 CONTINUE
      WRITE (6,534) NY1
      WRITE(6,526) ( HX(1,J),J=2,NY1)
```

```
      WRITE(6,535) NY1
      WRITE(6,526) ( HX(2,J),J=2,NY1)
      IF(N1.EQ.N2.AND.N3.EQ.N4) GO TO 95
      WRITE(6,536) N31,N41
      WRITE(6,526) ( HX(3,J),J=N31,N41)
      WRITE(6,537) N31,N41
      WRITE(6,526) ( HX(4,J),J=N31,N41)
      WRITE(6,401)
   95 CONTINUE
C
C     PRINT TITLE FOR SUBROUTINE CURVE OUTPUT
C
      WRITE(6,43)
   43 FORMAT(1H1,//,5X,'SUBROUTINE CURVE  -OUTPUT- '//5X,'I=0,OUTER BOUN
     1DARY. I=1,INNER BOUNDARY'/5X,'IP BOUNDARY PCINT NUMBER')
      WRITE(6,41)
   41 FORMAT(      /,5X,'(B2,C2) IS THE POINT ON THE BOUNDARY. (B1,C1) AN
     1D (B3,C3) ARE THE SURROUNDING POINTS ON BLADE. A,B,C, ARE THE COEF
     2S'/5X ,'OF THE PARBCLIC CURVE Y=A+B*X+C*X*X',//,4X,'I',3X,'IP',5X,
     3'B1',8X,'C1',8X,'B2',8X,'C2',8X,'B3',8X,'C3',9X,'A',9X,'B',9X,'C',
     4//)
 1    CONTINUE
C
C     STARTING OF GAUSS-SEIDELL METHOD OF ITERATION ON I LINES
C
      SUM=0.
      DO 250 I=2,NX1
      IL=IFIX(Y1(I)/DY+0.0001)+2
      IH=IFIX(Y2(I)/DY+0.0001)+1
      IF(ABS(Y2(I)-FLOAT(IH-1)*DY).LT.0.00001) IH=IH-1
C
C     OUTER LOWER BOUNDARY
C
       B2=FLOAT(I-1)*DX
       C2=Y1(I)
       CALL CUR(B2,C2,B,C,0)
       XMN=B+2.*C*B2
      IF(I.EQ.NX1) XMN=0.01
       YT=FLOAT(IL-1)*DY
       IF(ABS(XMN).LE.0.015)GO TC325
       X=(C2-YT)*XMN+B2
       IF(X.LE.B2)GO TO315
       XR=B2+DX
      IF((X2(IL)-XR).GT.0.0001) GO TO 324
       TTT=T(I,IL)+(TBX(2,IL)-T(I,IL))*(X-B2)/(X2(IL)-B2)
       GO TO 320
  324  CONTINUE
       TTT=T(I,IL)+(T(I+1,IL)-T(I,IL))*(X-B2)/DX
      GO TO 320
  315  TTT=T(I,IL)-(T(I,IL)-T(I-1,IL))*(B2-X)/DX
  320   XNL=(X-B2)*(X-B2)+(C2-YT)*(C2-YT)
      XNL=SQRT(XNL)
      GO TO 330
```

```
  325   TTT=T(I,IL)
        XNL=YT-C2
 330     AL=H(I,1)/XK
        TNEW=(XNL*AL*TG(I,1)+TTT)/(1.+XNL*AL)
        TNEW=(1.-OME)*TB(I,1)+OME*TNEW
        SUM=SUM+(TB(I,1)-TNEW)*(TB(I,1)-TNEW)
        TB(I,1)=TNEW
       IF(I.GT.N1.AND.I.LT.N2) GO TO 230
C
C
C    INTERIOR POINTS STARTING FROM LOWER END FOR I LINES WHICH DO NOT CUT
C    THE INNER BOUNDARY
C
       DO 210 J=IL,IH
       CALL MESH(I,J,TNEW)
       TNEW=(1.-OME)*T(I,J)+OME*TNEW
       SUM=SUM+(TNEW-T(I,J))*(TNEW-T(I,J))
 210   T(I,J)=TNEW
       GO TO 249
C
C
C      FOR I LINES INTERSECTING INNER BOUNDARY-ALL INTERIOR POINTS FROM
C    LOWER SURFACE OF OUTER BOUNDARY TO LOWER SURFACE OF INNER BOUNDARY
C
 230    CONTINUE
       ILI=IFIX(Y3(I)/DY+0.0001)+1
       IF(ABS(Y3(I)-FLOAT(ILI-1)*DY).LT.0.00001) ILI=ILI-1
       IHI=IFIX(Y4(I)/DY+0.0001)+2
       DO 235 J=IL,ILI
       CALL MESH(I,J,TNEW)
       TNEW=(1.-OME)*T(I,J)+OME*TNEW
       SUM=SUM+(TNEW-T(I,J))*(TNEW-T(I,J))
 235   T(I,J)=TNEW
C
C    INNER BOUNDARY - LOWER SURFACE
C
       B2=FLOAT(I-1)*DX
       C2=Y3(I)
       CALL CUR(B2,C2,B,C,1)
       XMN=B+2.*C*B2
       IF(I.EQ.N21) XMN=0.01
       YT=FLOAT(ILI-1)*DY
       IF(ABS(XMN).LE.0.015) GO TO 355
       X=(C2-YT)*XMN+B2
       IF(X.LE.B2) GO TO 350
       TTT=T(I,ILI)+(T(I+1,ILI)-T(I,ILI))*(X-B2)/DX
       GO TO 352
 350   TTT=T(I,ILI)-(T(I,ILI)-T(I-1,ILI))*(B2-X)/DX
 352   XNL=(X-B2)*(X-B2)+(C2-YT)*(C2-YT)
       XNL=SQRT(XNL)
       GO TO 358
  355 TTT=T(I,ILI)
       XNL=C2-YT
```

```
  358 AL=H(I,3)/XK
      TNEW=(XNL*AL*TG(I,3)+TTT)/(1.+XNL*AL)
      TNEW=(1.-OME)*TB(I,3)+OME*TNEW
      SUM=SUM+(TB(I,3)-TNEW)*(TB(I,3)-TNEW)
      TB(I,3)=TNEW
C
C   UPPER SURFACE OF INNER BOUNDARY
C
      C2=Y4(I)
      CALL CUR(B2,C2,B,C,1)
      XMN=B+2.*C*B2
      IF(I.EQ.N21) XMN=0.01
      YT=FLOAT(IHI-1)*DY
      IF(ABS(XMN).LE.0.015) GO TC 370
      X=(C2-YT)*XMN+B2
      IF(X.LE.B2) GO TO 360
      TTT=T(I,IHI)+(T(I+1,IHI)-T(I,IHI))*(X-B2)/DX
       GO TO 365
 360   TTT=T(I,IHI)-(T(I,IHI)-T(I-1,IHI))*(B2-X)/DX
 365   XNL=(X-B2)*(X-B2)+(C2-YT)*(C2-YT)
      XNL=SQRT(XNL)
      GO TO 375
 370   TTT=T(I,IHI)
      XNL=YT-C2
 375   AL=H(I,4)/XK
      TNEW=(XNL*AL*TG(I,4)+TTT)/(1.+XNL*AL)
      TNEW=(1.-CME)*TB(I,4)+CME*TNEW
      SUM=SUM+(TB(I,4)-TNEW)*(TB(I,4)-TNEW)
      TB(I,4)=TNEW
C
C
C   INTERIOR POINTS FROM UPPER SURFACE OF INNER BCUNDARY TO THE UPPER
C   SURFACE OF OUTER BOUNDARY
C
      DO 240 J=IHI,IH
      CALL MESH(I,J,TNEW)
      TNEW=(1.-OME)*T(I,J) +CME*TNEW
      SUM=SUM+(TNEW-T(I,J))*(TNEW-T(I,J))
 240  T(I,J)=TNEW
  249  CONTINUE
C
C   UPPER BOUNDARY OF CUTER SURFACE
C
       C2=Y2(I)
       CALL CUR(B2,C2,B,C,0)
      XMN=B+2.*C*B2
      IF(I.EQ.NX1) XMN=0.01
      YT=FLOAT(IH-1)*DY
      IF(ABS(XMN).LE.0.015) GO TC 340
      X=(C2-YT)*XMN+B2
       XL=B2-DX
      IF((XL-X1(IH)).GT.0.00001) GC TO 336
       TTT=T(I,IH)-(T(I,IH)-TBX(1,IH))*(B2-X)/(B2-X1(IH))
```

```
      GO TO 337
  336 CONTINUE
      IF(X.LE.B2) GO TO 335
      TTT=T(I,IH)+(T(I+1,IH)-T(I,IH))*(X-B2)/DX
      GO TO 337
  335 TTT=T(I,IH)-(T(I,IH)-T(I-1,IH))*(B2-X)/DX
  337 XNL=(X-B2)*(X-B2)+(C2-YT)*(C2-YT)
      XNL=SQRT(XNL)
      GO TO 345
  340 TTT=T(I,IH)
      XNL=C2-YT
  345 AL=H(I,2)/XK
      TNEW=(XNL*AL*TG(I,2)+TTT)/(1.+XNL*AL)
      TNEW=(1.-OME)*TB(I,2)+OME*TNEW
      SUM=SUM+(TB(I,2)-TNEW)*(TB(I,2)-TNEW)
      TB(I,2)=TNEW
  250 CONTINUE
C
C     ITER. FOR J LINES ONLY BOUNDARY POINTS INTERSECTED BY J LINES
C
      DO 490 J=2,NY1
      IN =IFIX(X1(J)/DX+0.0001)+2
      IA =IFIX(X2(J)/DX+0.0001)+1
       IF(ABS(X2(J)-FLOAT(IA-1)*DX).LT.0.00001) IA=IA-1
C
C   NEAR SURFACE OF OUTER BOUNDARY
C
       B2=X1(J)
      C2=FLOAT(J-1)*DY
      CALL CUR(B2,C2,B,C,0)
      XMN=B+2.*C*B2
       XT=FLOAT(IN-1)*DX
       IF(ABS(XMN).GE.5.)GO TO 410
       XL=XT-DX
       X=-DY*XMN+B2
      IF(X.LE.B2) GO TO 406
      IF((X2(J+1)-XT).GT.0.0001) GC TO 405
       TTT=T(IN-1,J+1)+(TBX(2,J+1)-T(IN-1,J+1))*(X-XL)/(X2(J+1)-XL)
        GO TO 407
  405 CONTINUE
       TTT=T(IN,J+1)+(T(IN-1,J+1)-T(IN,J+1))*(XT-X)/DX
      GO TO 407
  406 CONTINUE
      X=DY*XMN+B2
      TTT=T(IN,J-1)+(TBX(1,J-1)-T(IN,J-1))*(XT-X)/(XT-X1(J-1))
  407  XNL=(B2-X)*(B2-X)+DY*DY
       XNL=SQRT(XNL)
      GO TO 415
  410  TTT=T(IN,J)
      XNL=XT-B2
  415 AL=HX(1,J)/XK
      TNEW=(TTT+AL*XNL*TGX(1,J))/(1.+XNL*AL)
      TNEW=(1.-OME)*TBX(1,J)+OME*TNEW
```

```
      SUM=SUM+(TNEW-TBX(1,J))*(TNEW-TBX(1,J))
      TBX(1,J)=TNEW
      IF(J.GT.N3.AND.J.LT.N4) GO TO 418
      GO TO 445
C
C
C   FOR J LINES INTERSECTING INNER BOUNDARY-BOUNDARY POINTS ON THE
C   NEARER SURFACE OF INNER BOUDARY
C
C
 418   CONTINUE
      INI=IFIX(X3(J)/DX+0.0001)+1
      IF(ABS(X3(J)-FLOAT(INI-1)*DX).LT.0.00001) INI=INI-1
      IAI=IFIX(X4(J)/DX+0.0001)+2
      B2=X3(J)
      CALL CUR(B2,C2,B,C,1)
      XMN=B+2.*C*B2
      XT=FLOAT(INI-1)*DX
       IF(ABS(XMN).GE.5.)GO TO 425
        X=DY*XMN+B2
      IF(X.GT.B2) GO TO 421
       TTT=T(INI,J-1)+(T(INI+1,J-1)-T(INI,J-1))*(X-XT)/DX
       GO TO 422
  421 X=-DY*XMN+B2
      TTT=T(INI,J+1)+(T(INI,J+1)-T(INI+1,J+1))*(X-XT)/DX
  422  XNL=(B2-X)*(B2-X)+DY*DY
       XNL=SQRT(XNL)
      GO TO 426
 425   TTT=T(INI,J)
      XNL=B2-XT
 426   AL=HX(3,J)/XK
      TNEW=(TTT+AL*XNL*TGX(3,J))/(1.+XNL*AL)
      TNEW=(1.-OME)*TBX(3,J)+OME*TNEW
      SUM=SUM+(TNEW-TBX(3,J))*(TNEW-TBX(3,J))
      TBX(3,J)=TNEW
C
C   FARTHER SURFACE OF INNR  BOUNDARY
C
      B2=X4(J)
      CALL CUR(B2,C2,B,C,1)
      XMN=B+2.*C*B2
      IF(J.EQ.N31) XMN=6.0
      XT=FLOAT(IAI-1)*DX
       IF(ABS(XMN).GE.5.)GO TO 435
       X=-DY*XMN+B2
       TTT=T(IAI,J+1)+(T(IAI-1,J+1)-T(IAI,J+1))*(XT-X)/DX
  430  XNL=(B2-X)*(B2-X)+DY*DY
       XNL=SQRT(XNL)
      GO TO 440
 435  TTT=T(IAI,J)
      XNL=XT-B2
 440   AL=HX(4,J)/XK
      TNEW=(TTT+AL*XNL*TGX(4,J))/(1.+XNL*AL)
```

```
      TNEW=(1.-OME)*TBX(4,J)+OME*TNEW
      SUM=SUM+(TNEW-TBX(4,J))*(TNEW-TBX(4,J))
      TBX(4,J)=TNEW
C
C   FARTHER BOUNDARY POINTS ON OUTER SURFACE
C
 445  B2=X2(J)
      CALL CUR(B2,C2,B,C,0)
      XMN=B+2.*C*B2
      IF(J.EQ.2   ) XMN=6.0
      XT=FLOAT(IA-1)*DX
      IF(ABS(XMN).GE.5.) GO TO 455
       XR=XT+DX
       X=DY*XMN+B2
      IF((XT-X1(J-1)).GT.0.00001) GO TO 450
       TTT=TBX(1,J-1)-(TBX(1,J-1)-T(IA+1,J-1))*(X-X1(J-1))/(XR-X1(J-1))
       GO TO 452
  450 CONTINUE
       TTT=T(IA,J-1)+(T(IA+1,J-1)-T(IA,J-1))*(X-XT)/DX
  452  XNL=(B2-X)*(B2-X)+DY*DY
       XNL=SQRT(XNL)
      GO TO 460
 455   TTT=T(IA,J)
      XNL=B2-XT
 460   AL=HX(2,J)/XK
      TNEW=(TTT+AL*XNL*TGX(2,J))/(1.+XNL*AL)
      TNEW=(1.-OME)*TBX(2,J)+OME*TNEW
      SUM=SUM+(TBX(2,J)-TNEW)*(TBX(2,J)-TNEW)
      TBX(2,J)=TNEW
 490   CONTINUE
      DO 495 I=1,NX1
      DO 495 J=1,NY1
      X=FLOAT(I-1)*DX
      TB(1,1)=TBX(1,J)
      Y=FLOAT(J-1)*DY
      IF(ABS(X-X1(J)).LT.0.00001.AND.ABS(Y-Y1(I)).LT.0.00001) T(I,J)=TB(
     1I,1)
      IF(ABS(X-X1(J)).LT.0.00001.AND.ABS(Y-Y2(I)).LT.0.00001) T(I,J)=TB(
     1I,1)
      IF(ABS(X-X2(J)).LT.0.00001.AND.ABS(Y-Y2(I)).LT.0.00001) T(I,J)=TB(
     1I,2)
  495 CONTINUE
C
C
C
C   COMPLETION OF AN ITERATION-CHECKS FOR REQUIRED CONVERGENCE
C
C
      IF(ITER.EQ.1) WRITE(6,509)
  509 FORMAT(1H1)
      WRITE(6,510) ITER,SUM
  510 FORMAT(5X,'ITERATION=',I3,3X,'ERROR=',
     1 E12.5)
```

```
      IF(ITER/NTE*NTE.EQ.ITER) GO TO 520
      IF(SUM.LE.SUMM) GO TO 520
      IF(ITER.GE.IMAX) GO TO 600
      ITER=ITER+1
      GO TO 1
  520 CONTINUE
      WRITE(6,540)
  540 FORMAT(1H1//////9X,'TEMPERATURE DISTRIBUTION IN A HOLLOW BLADE  '
     1'///////)
      WRITE(6,541)DX,DY,OME,XK,NX,NY,SUMM,N1,N2,N3,N4,NXO,NXI
  541 FORMAT(3X,'DX =',F8.5,5X,'DY =',F8.5,5X,'OMEGA=',F8.5,5X,'THRM.CON
     1D.=',F8.5/3X,'NX =',I8,5X,'NY =',I8,5X,'MAX.ERROR=',F8.5/3X,'N1 ='
     2,I8,5X,'N2 =',I8,5X,'N3 =',I8,5X,'N4 =',I8/3X,'NXO =',I8,5X,'NXI =
     3',I6/1H1)
      WRITE(6,522)
  522 FORMAT(//,10X,'T-MATRIX,GIVES ALL INTERIOR POINTS.INITIAL SETTING
     1 OF T IS 1600.0'/10X,'ONLY THOSE INSIDE BLADE ARE CHANGED AND WILL
     2 BE DIFFERENT FROM 1600.00')
      WRITE(6,523)
  523 FORMAT(/,2X,'J =',4X,'1',7X,'2',7X,'3',7X,'4',7X,'5',7X,'6',7X, '7
     1',7X,'8',7X,'9',6X,'10',6X,'11',6X,'12',6X,'13',6X,'14',6X,'15'/
     22X,'I')
      IF(NY.GT.15) WRITE(6,521)
  521 FORMAT(8X,'16',6X,'17',6X,'18',6X,'19',6X,'20' ,6X,'21',6X,'22',6X
     1,'23',6X,'24',6X,'25')
      DO 603 I=1,NX
  603 WRITE(6,525) I,(T(I,J),J=1,NY)
  525 FORMAT(/,2X,I2,1X,15F8.2,2(/5X,15F8.2))
      WRITE(6,524)
  524 FORMAT('1',//,5X,'TEMPERATURE DISTRIBUTION ON THE BOUNDARY',////)
      WRITE(6,530)  NX1
  530 FORMAT(//,10X,'BOUNDARY POINTS ON I-LINES FOR LOWER SURFACE  OF
     1 OUTER BOUNDRY'/,12X,'(START FROM I= 2  TO   I=',I3,' )')
      WRITE(6,525) (TB(I,1),I=1,NX1)
      WRITE(6,531) NX1
  531 FORMAT(//,10X,'BOUNDARY POINTS ON I LINES FOR UPPER SURFACE  OF
     1 OUTER BOUNDRY'/,12X,'(START FROM I= 2  TO I=',I3,' )')
      WRITE(6,525) (TB(I,2),I=1,NX1)
      IF(N1.EQ.N2.AND.N3.EQ.N4) GO TO 87
      WRITE (6,532) N11,N21
  532 FORMAT(//,10X,'BOUNDARY POINTS ON I LINES FOR LOWER SURFACE OF
     1 INNER BOUNDARY'/,12X,'(START FROM I=',I3,'   TO   I=',I3,' )')
      WRITE(6,526)(TB(I,3),I=N11,N21)
      WRITE(6,533) N11,N21
  533 FORMAT(//,10X,'BOUNDARY POINTS ON I LINES FOR UPPER SURFACE OF
     1 INNER BOUNDARY'/,12X,'(START FROM I=',I3,'   TO   I=',I3,' )')
      WRITE(6,526)(TB(I,4),I=N11,N21)
   87 CONTINUE
      WRITE (6,534) NY1
  534 FORMAT(//,10X,'BOUNDARY POINTS ON J LINES FOR NEARER SURFACE OF
     1 OUTER BOUNDARY'/,12X,'(START FROM J= 2  TO   J=',I3,' )')
      WRITE(6,526)(TBX(1,J),J=2,NY1)
      WRITE(6,535) NY1
```

```
  535 FORMAT(//,10X,'BOUNDARY POINTS ON J LINES FOR FARTHER SURFACE OF
     1 OUTER BOUNDARY'/,12X,'(START FROM J= 2  TO  J=',I3,' )')
      WRITE(6,526)(TBX(2,J),J=2,NY1)
      IF(N1.EQ.N2.AND.N3.EQ.N4) GO TO 89
      WRITE(6,536) N31,N41
  536 FORMAT(//,10X,'BOUNDARY POINTS ON J LINES FOR NEARER SURFACE OF
     1INNER BOUNDARY '/12X,'(START FROM J=',I3,'  TO  J=',I3,' )')
      WRITE(6,526)(TBX(3,J),J=N31,N41)
      WRITE(6,537) N31,N41
  537 FORMAT(//,10X,'BOUNDARY POINTS ON J LINES FOR FARTHER SURFACE OF
     1INNER BOUNDARY '/12X,'(START FROM J=',I3,'  TO  J=',I3,' )')
      WRITE(6,526)(TBX(4,J),J=N31,N41)
      WRITE(6,401)
  401 FORMAT(1H1)
  526 FORMAT(3(/,5X,15F8.2))
   89 CONTINUE
      WRITE (6,801)
      DO 701  J1=2,NY1
      DO 702  I=1,NX
      J=NY+1-J1
      XR=FLOAT(I-1)*DX
      IF(    (XR-X1(J)).GE.0.0001)  I1=I
      IF(ABS(XR-X1(J)).LE.0.0001)  I1=I+1
      IF(    (XR-X1(J)).GE.0.0001)  GO TO 704
  702 CONTINUE
  704 DO 703  I=I1,NX
      XR=FLOAT(I-1)*DX
      IF(    (XR-X2(J)).GE.0.0001)  I2=I-1
      IF(ABS(XR-X2(J)).GE.(0.9999*DX))  I2=I2-1
      IF(    (XR-X2(J)).GE.0.0001)  GO TO 705
  703 CONTINUE
  705 CONTINUE
      J=NY+1-J1
      IF(J.EQ.2 )  WRITE(6,824)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.3 )  WRITE(6,823)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.4 )  WRITE(6,822)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.5 )  WRITE(6,821)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.6 )  WRITE(6,820)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.7 )  WRITE(6,819)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.8 )  WRITE(6,818)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.9 )  WRITE(6,817)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.10)  WRITE(6,816)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.11)  WRITE(6,815)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.12)  WRITE(6,814)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.13)  WRITE(6,813)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.14)  WRITE(6,812)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.15)  WRITE(6,811)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.16)  WRITE(6,810)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.17)  WRITE(6,809)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.18)  WRITE(6,808)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.19)  WRITE(6,807)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.20)  WRITE(6,806)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.21)  WRITE(6,805)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
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      IF(J.EQ.22) WRITE(6,804)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.23) WRITE(6,803)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
      IF(J.EQ.24) WRITE(6,802)J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
  801 FORMAT(1H1///,15X,'TEMPERATURE DISTRIBUTION INSIDE THE BLADE AND O
     XN ITS SURFACE'///2X,'J=')
  802 FORMAT(/2X,I2, 4X,20F8.2)
  803 FORMAT(/2X,I2, 6X,20F8.2)
  804 FORMAT(/2X,I2, 8X,20F8.2)
  805 FORMAT(/2X,I2,10X,13F8.2/24X,7F8.2)
  806 FORMAT(/2X,I2,12X,13F8.2/24X,7F8.2)
  807 FORMAT(/2X,I2,14X,13F8.2/24X,7F8.2)
  808 FORMAT(/2X,I2,16X,13F8.2/24X,7F8.2)
  809 FORMAT(/2X,I2,18X,13F8.2/24X,7F8.2)
  810 FORMAT(/2X,I2,20X,20F8.2)
  811 FORMAT(/2X,I2,22X,20F8.2)
  812 FORMAT(/2X,I2,24X,20F8.2)
  813 FORMAT(/2X,I2,26X,20F8.2)
  814 FORMAT(/2X,I2,28X,20F8.2)
  815 FORMAT(/2X,I2,30X,20F8.2)
  816 FORMAT(/2X,I2,32X,20F8.2)
  817 FORMAT(/2X,I2,34X,20F8.2)
  818 FORMAT(/2X,I2,36X,20F8.2)
  819 FORMAT(/2X,I2,38X,20F8.2)
  820 FORMAT(/2X,I2,40X,20F8.2)
  821 FORMAT(/2X,I2,42X,20F8.2)
  822 FORMAT(/2X,I2,44X,20F8.2)
  823 FORMAT(/2X,I2,46X,20F8.2)
  824 FORMAT(/2X,I2,48X,20F8.2)
  701 CONTINUE
      IF(SUM.LE.SUMM) GO TO 600
      ITER=ITER+1
      GO TO 1
 600  CONTINUE
  633 WRITE(6,665)
  665 FORMAT(1H1,38X,'ISOTHERMAL LINE LOCATIONS '/,9X,'I',4X,'J',3X,'T',
     14X,'T - 1',6X,'T - 2  ',8X,'FRAC',/)
      DO 601 I=2,NX1
      IA=IFIX(Y1(I)/DY+0.0001)+1
      IB=IFIX(Y3(I)/DY+0.0001)+2
      IC=IFIX(Y4(I)/DY+0.0001)+1
      ID=IFIX(Y2(I)/DY+0.0001)+2
      IB=IB-1
      ID=ID-1
      IF(I.GT.N1.AND.I.LT.N2) GO TO 629
      IT1=TB(I,1)
      IT2=TB(I,2)
      IL=IT1
      IH=IT2
      IF(IT1.GE.IT2) IL=IT2
      IF(IT1.GE.IT2) IH=IT1
      IAA=IA
      DO 623 J=IAA,ID
      IF(T(I,J).LT.FLOAT(IL)) IL=IFIX(T(I,J))
```

```
      IF(T(I,J).GT.FLOAT(IH))IH=IFIX(T(I,J))
  620 CONTINUE
  623 CONTINUE
      DO 624 II=IL,IH
      DO 625 J=IA,ID
      IF((FLOAT(J  )*DY).GT.Y2(I)) T(I,J+1)=TB(I,2)
      IF(Y1(I).GT.(FLOAT(J-1)*DY)) T(I,J)=TB(I,1)
      TV=FLOAT(II)
      IF(T(I,J).LT.TV.AND.T(I,J+1).GE.TV) GO TO 627
      IF(T(I,J).GE.TV.AND.T(I,J+1).LT.TV) GO TO 627
      GO TO 625
  627 CONTINUE
      RX=(T(I,J)-TV)/(T(I,J)-T(I,J+1))
      WRITE(6,666) I,J,II,T(I,J),T(I,J+1),RX
  625 CONTINUE
  624 CONTINUE
      GO TO 601
  629 CONTINUE
      IT1=TB(I,1)
      IT2=TB(I,3)
      IT3=TB(I,4)
      IT4=TB(I,2)
      IL=IT1
      IH=IT2
      IL1=IT3
      IH1=IT4
      IF(IT1.GE.IT2) IL=IT2
      IF(IT1.GE.IT2) IH=IT1
      IF(IT3.GE.IT4) IL1=IT4
      IF(IT3.GE.IT4) IH1=IT3
      DO 604 II=IL,IH
      DO 605 J=IA,IB
      TV=FLOAT(II)
      IF(Y1(I).GT.(FLOAT(J-1)*DY)) T(I,J)=TB(I,1)
      IF((FLOAT(J  )*DY).GT.Y3(I)) T(I,J+1)=TB(I,3)
      IF(T(I,J).LT.TV.AND.T(I,J+1).GE.TV) GO TO 607
      IF(T(I,J).GE.TV.AND.T(I,J+1).LT.TV) GO TO 607
      GO TO 605
  607 RX=(T(I,J)-TV)/(T(I,J)-T(I,J+1))
      WRITE(6,666) I,J,II,T(I,J),T(I,J+1),RX
  666 FORMAT(5X,3I5,3F11.4)
  605 CONTINUE
  604 CONTINUE
      DO 614 II=IL1,IH1
      DO 615 J=IC,ID
      TV=FLOAT(II)
      IF(Y4(I).GT.(FLOAT(J-1)*DY)) T(I,J)=TB(I,4)
      IF((FLOAT(J-1)*DY).GT.Y2(I)) T(I,J+1)=TB(I,2)
      IF(T(I,J).LT.TV.AND.T(I,J+1).GE.TV) GO TO 617
      IF(T(I,J).GE.TV.AND.T(I,J+1).LT.TV) GO TO 617
      GO TO 615
  617 RX=(T(I,J)-TV)/(T(I,J)-T(I,J+1))
      WRITE(6,666) I,J,II,T(I,J),T(I,J+1),RX
```

```
  615 CONTINUE
  614 CONTINUE
  601 CONTINUE
  649 CONTINUE
      STOP
      END
```

```
      SUBROUTINE MESH(I,J,TNEW)
      COMMON T(40,25),TB(40,4),TBX(4,25),TG(40,4),TGX(4,25),H(40,4),HX(4
     1,25),Y1(40),Y2(40),Y3(40),Y4(40),X1(25),X2(25),X3(25),X4(25),BX(12
     20),BY(120),BXI(120),BYI(120),IP(120)
      COMMON DX,DY,NX,NY,NXO,NXI,ITER,N1,N2,N3,N4
C
C
C    SUBROUTINE FINDS SI-1,SI-2,DEL-U,DEL-2. FOR EACH INTERIOR POINT AND
C    GETS NEW TEMPS FOR EVERY INTERIOR POINT
C
C
      PAR=FLOAT(I-1)*DX
      IF((PAR-X1(J)).LE.DX)S1=(PAR-X1(J))/DX
      IF((PAR-X1(J)).LE.DX)T1=TBX(1,J)
      IF ((PAR-X1(J)).LE.DX) GO TO 20
      IF(J.GT.N3.AND.J.LT.N4)GO TO 10
       GO TO 15
   10 IF(PAR.GE.X4(J))GO TO 12
       GO TO 15
 12     IF((PAR-X4(J)).LE.DX)S1=(PAR-X4(J))/DX
      IF((PAR-X4(J)).LE.DX)T1=TBX(4,J)
      IF ((PAR-X4(J)).LE.DX) GO TO 20
   15  S1=1.0
      T1=T(I-1,J)
      IF(ABS(X1(J)-PAR+DX).LT.0.00001) T1=TBX(1,J)
      IF(ABS(X4(J)-PAR+DX).LT.0.00001) T1=TBX(4,J)
   20  CONTINUE
      IF((X2(J)-PAR).LE.DX)S2=(X2(J)-PAR)/DX
      IF((X2(J)-PAR).LE.DX) T3=TBX(2,J)
      IF((X2(J)-PAR).LE.DX) GO TO 35
      IF(J.GT.N3.AND.J.LT.N4)GO TO25
      GO TO 30
 25     IF(X3(J).GT.PAR)GO TO 27
      GO TO 30
 27     IF((X3(J)-PAR).LE.DX)S2=(X3(J)-PAR)/DX
      IF((X3(J)-PAR).LE.DX)T3=TBX(3,J)
      IF((X3(J)-PAR).LE.DX) GO TO 35
   30  S2=1.
      T3=T(I+1,J)
      IF(ABS(X2(J)-PAR-DX).LT.0.00001) T3=TBX(2,J)
      IF(ABS(X3(J)-PAR-DX).LT.0.00001) T3=TBX(3,J)
 35     PAR=FLOAT(J-1)*DY
       IF((PAR-Y1(I)).LE.DY)D1=(PAR-Y1(I))/DY
       IF((PAR-Y1(I)).LE.DY)T2=TB(I,1)
      IF((PAR-Y1(I)).LE.DY) GO TO 50
       IF(I.GT.N1.AND.I.LT.N2)GO TO40
      GO TO 45
   40  IF(PAR.GE.Y4(I))GO TO42
      GO TO 45
   42  IF((PAR-Y4(I)).LE.DY)D1=(PAR-Y4(I))/DY
       IF((PAR-Y4(I)).LE.DY)T2=TB(I,4)
      IF((PAR-Y4(I)) LE.DY) GO TO 50
   45  D1=1.0
```

```
      T2=T(I,J-1)
      IF(ABS(Y1(I)-PAR+DY).LT.0.00001) T2=TB(I,1)
      IF(ABS(Y4(I)-PAR+DY).LT.0.00001) T2=TB(I,4)
   50 CONTINUE
      IF((Y2(I)-PAR).LE.DY)D2=(Y2(I)-PAR)/DY
      IF((Y2(I)-PAR).LE.DY)T4=TB(I,2)
      IF((Y2(I)-PAR).LE.DY) GO TO 65
      IF(I.GT.N1.AND.I.LT.N2)GO TO55
      GO TO 60
   55 IF(Y3(I).GT.PAR)GO TO57
      GO TO 60
   57 IF((Y3(I)-PAR).LE.DY)D2=(Y3(I)-PAR)/DY
      IF((Y3(I)-PAR).LE.DY)T4=TB(I,3)
      IF((Y3(I)-PAR).LE.DY) GO TO 65
   60 D2=1.0
      T4=T(I,J+1)
      IF(ABS(Y2(I)-PAR-DY).LT.0.00001) T4=TB(I,2)
      IF(ABS(Y3(I)-PAR-DY).LT.0.00001) T4=TB(I,3)
   65 CONTINUE
      A1=T1/S1/(S1+S2)
      A2=T2/D1/(D1+D2)
      A3=T3/S2/(S1+S2)
      A4=T4/D2/(D1+D2)
      E=1./S1/S2+(DX/DY)*(DX/DY)/D1/D2
      TNEW=(A1+A3+DX*DX/(DY*DY)*(A2+A4))/E
      RETURN
      END
```

```
      SUBROUTINE SLO(X1,Y1,X2,Y2,X3,Y3,A,B,C)
C
C
C   FINDS EQUATION THRU THREE POINTS AS Y=A+B$X+C*X*X
C
C
      CALL UNDFLW
      IF(ABS(X1-X2).LE.0.001.AND.ABS(X2-X3).LE.0.001) GO TO 10
      XS3=X3*X3
      XS2=X2*X2
      XS1=X1*X1
      D1=X2*XS3-X3*XS2
      D2=X1*XS3-X3*XS1
      D3=X1*XS2-X2*XS1
      D=D1-D2+D3
       IF(ABS(D).LE.0.000001) GO TO 10
      A1=Y1*(X2*XS3-X3*XS2)
      A2=Y2*(X1*XS3-X3*XS1)
      A3=Y3*(X1*XS2-X2*XS1)
      A=(A1-A2+A3)/D
      B1=Y2*XS3-Y3*XS2
      B2=Y1*XS3-Y3*XS1
      B3=Y1*XS2-Y2*XS1
      B=(B1-B2+B3)/D
      C1=X2*Y3-X3*Y2
      C2=X1*Y3-X3*Y1
      C3=X1*Y2-X2*Y1
      C=(C1-C2+C3)/D
      RETURN
 10   A=100.
      B=100.
      C=100.
       RETURN
      END
```

```
      SUBROUTINE CUR(B2,C2,B,C,I)
      COMMON T(40,25),TB(40,4),TBX(4,25),TG(40,4),TGX(4,25),H(40,4),HX(4
     1,25),Y1(40),Y2(40),Y3(40),Y4(40),X1(25),X2(25),X3(25),X4(25),BX(12
     20),BY(120),BXI(120),BYI(120),IP(120)
      COMMON DX,DY,NX,NY,NXO,NXI,ITER,N1,N2,N3,N4
C
C
C
C    SUBROUTINE TO FIND ADJACENT TWO POINTS FOR THE POINT(B2,C2) AND THEN
C    PASSES A CURVE Y=A+BX+CX2 AND DETERMINES A,B,C. B,C COEFFICIENTS
C    ARE RETURNED TO MAIN PROGRAM TO GET SLOPE OF CURVED BOUNDARY AT THE
C    POINT
C
C
C
      IF(I.EQ.1)GO TO 25
      DO 10 M=1,NXO
      IF(ABS(B2-BX(M)).LE.0.0001.AND.ABS(C2-BY(M)).LE.0.0001) GO TO 12
   10 CONTINUE
 12   IF(M.EQ.1) GO TO 15
      B1=BX(M-1)
      C1=BY(M-1)
      GO TO 13
 15   B1=BX(NXO)
      C1=BY(NXC)
 13   CONTINUE
      B3 = BX(M+1)
      C3 = BY(M+1)
      IF(M.EQ.NXO) B3=BX(1)
      IF(M.EQ.NXO) C3=BY(1)
      IF(B3.EQ.B2.AND.C3.EQ.C2)GC TO 14
      GO TO 37
   14 B3 = BX(M+2)
      C3 = BY(M+2)
      GO TO 37
   25 DO 30 M = 1,NXI
      IF(B2.EQ.BXI(M).AND.C2.EQ.BYI(M))GO TO 32
   30 CONTINUE
 32   IF(M.EQ.1) GO TO 34
      B1=BXI(M-1)
      C1=BYI(M-1)
       IF(M.EQ.17) B1=5.8
       IF(M.EQ.17) C1=1.74
      GO TO 33
 34    B1=BXI(NXI)
      C1=BYI(NXI)
 33   CONTINUE
      B3=BXI(M+1)
      C3=BYI(M+1)
      IF(M.EQ.NXI) B3=BXI(1)
      IF(M.EQ.NXI) C3=BYI(1)
      IF(B3.EQ.B2.AND.C3.EQ.C2)GO TO 35
      GO TO 37
```

```
   35 B3=BXI(M+2)
      C3=BYI(M+2)
   37 CALL SLO(B1,C1,B2,C2,B3,C3,A,B,C)
      IF(ITER.EQ.1) WRITE(6,40)I,M,B1,C1,B2,C2,B3,C3,A,B,C
   40 FORMAT(  3X,I2,I5,9F10.5)
      RETURN
      END
```